Deliverable 2.3: Recommendation and selection of BIM tools and standards for information exchange to be used by demo sites

WP2. New methodological approach for E2B design, construction and operation

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[1] **PU**=Public, **PP**=Restricted to other programme participants (including the Commission Services), **RE**=Restricted to a group specified by the consortium (including the Commission Services), **CO**=Confidential, only for members of the consortium (including the Commission Services)

Executive Summary

The **objective** of the Deliverable 2.3 "Recommendation and selection of BIM tools and standards for information exchange to be used by the demo sites" is to provide guidelines for BIM-based energy analysis and information exchange and support demosites in choosing a properly BIM tool.

The Deliverable D2.3 covers the overall work performed within task T2.3 "BIM tools selection to low energy building design, construction and operation" of WP2. It supports the NEED4B methodology to be developed in tasks 2.5 and task 2.6.

It is structured into **six parts**.

In **part one**, the current Building Information Modeling (BIM) software landscape is analyzed in order to identify the energy analysis functionalities which are included in those tools. Then they are mapped with usual functionalities of current energy tools used by the stakeholders in order to figure out which simulations are already possible to process with BIM and whether they complement or replace the current ones.

Part two and **part three** provide the analysis of the exchange process between BIM software and energy analysis and simulation software, including the data schemas or formats. Some proof of concept have been performed in order to support this study, testing how well applications talk to one another since not every application is interoperable with all of the other and also what and how data should be defined in a BIM so that software applications can exchange it reliably.

Part four and part five comprise the main section of the Deliverable report. It is intended to provide guidance to stakeholders using BIM technology in the design of energy efficiency buildings, supporting the election of software and subsequently the development of Building Information Models.

Part six describes the workflow to be followed by demo sites design and construction teams in order to achieve the design of energy efficient buildings through the use of the BIM methodology.

All partners were involved and each partner has contributed from their expert viewpoint as follows:

- ACCIONA: Leader, all task from BIM expert and contractor point of view and the editing of the overall report.
- DEROME: Section 1.3, mapping of BIM and usual tools, and section 3, with focus especially on the part 3.3, exchange test with IFC schema.
- OZU, DAPPO, FD2, FIBA: Contributions to section 1.3, mapping of BIM and usual tools.

1 BIM tools and their energy analysis in-built functionalities

1.1 BIM tools

Building Information Modeling (BIM) is both the creation of a set of digital models of a planned or built environment, as well as the process of working collaboratively with these models during the lifecycle of that building. In order to support these creation and collaboration, integrated software tools are now commercially available.

BIM applications can be considered as tools for generating design information, structuring it and managing it. However, currently most BIM design applications also have interfaces to other functionalities as, for instance, rendering, energy analysis or cost estimation.

Energy analysis and simulation tools associated with low carbon building design and sustainability are usually very numerical and not visually compelling. However the 'green BIM' features included in some BIM tools are a great way to provide visual feedback within the context of a design whether as a means to communicate a design choice, or as part of a presentation.

Different types of software (from different manufactures) can be used in the different phases and by different stakeholders. Examples of BIM tools are ArchiCAD, Allplan, Vectorworks, DDS-CAD or Revit, among others. However, for this task 2.3, only ArchiCAD, Revit platform (including Vasari) and DDS-CAD will be evaluated. The main arguments for this are that:

Revit, ArchiCAD and DDS-CAD have some interesting energy analysis capabilities and are widely used in Architecture, Engineering and Construction industry, holding a dominant market position. Actually, DDS-CAD is broadly used in the Nordic countries.

Also, they show a promising future evolution with enhancements that are released regularly, at least annually.

Furthermore, these tools provide a user-friendly interface, well organized according to workflow and they are easy to learn.

Revit and ArchiCAD have, also, open API which provides good support for external and ad-hoc application development.

Additionally, in the particular case of Revit platform, there is more improved links from Revit and Vasari to energy simulation tools like Green Building Studio or Ecotect than from others BIM tools.

Based on the results of task 1.3 surveys[2], it has been found that there is a great variability of energy analysis and simulation software tools used by the partners. In addition, not all of them are implementing BIM in their workflow. For that reason, exchange formats between BIM tools and traditional and advanced energy tools will be a key concept in NEED4B methodology. Indeed, this issue will be addressed in the part b of the current task 2.3.

A short summary of the chosen BIM tools for evaluation is included below:

- REVIT[3]: It is the best-known and current market leader for BIM in architectural design. The current version is Revit 2013, which includes into the same interface Revit Architecture, Revit MEP and Revit Structure (these products were split in previous versions). Revit supports the development of new custom parametric objects and customization of predefined objects.

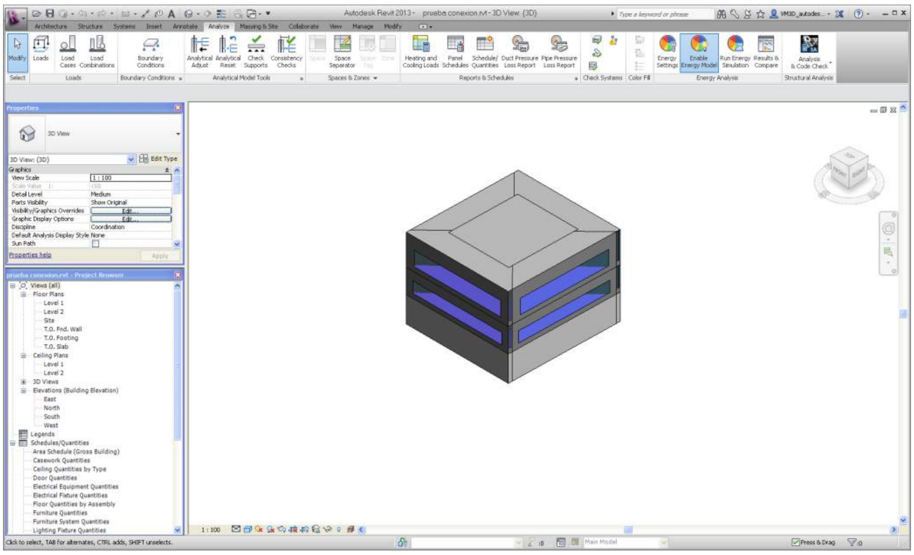


Figure 1: Revit interface screenshot

- VASARI[4]: This tool is considered as part of the Revit platform; however it works independently from Revit and is available as a free download and trial on Autodesk Labs. It is focused on conceptual building design using both geometric and parametric modeling. It supports performance-based design via integrated energy modeling and analysis cloud-based features.

[2] See Appendix A: Summary of software surveys carried out in Task 1.3

[3] http://usa.autodesk.com/revit/

[4] http://labs.autodesk.com/utilities/vasari/

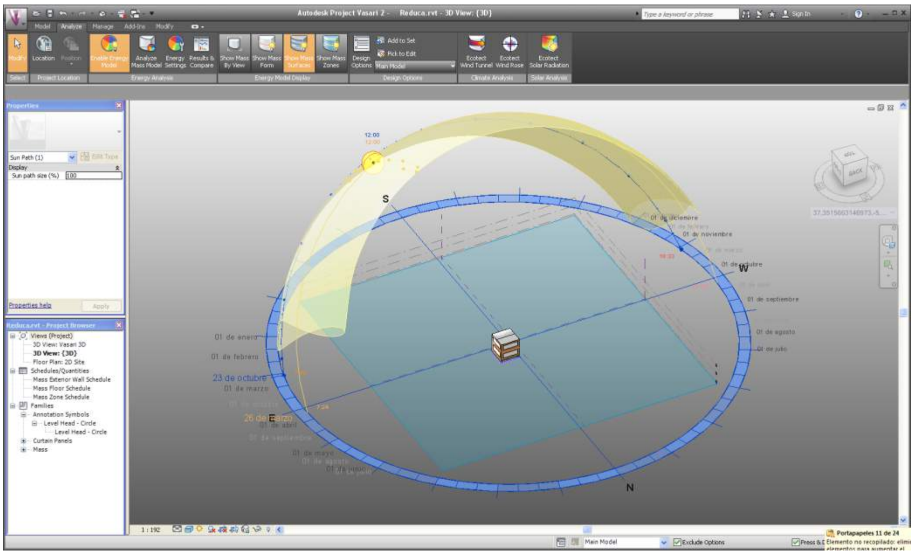


Figure 2: Vasari interface screenshot

- ARCHICAD[5]: It is the oldest continuously marketed BIM application for architectural design. The current version is ArchiCAD 16. In contrast to Revit platform, it supports the generation of custom parametric objects through its Geometric Description Language (GDL) scripting language, which is less intuitive and easy to use than parametric graphical design allowed by Revit. The built-in Energy Evaluation functionality of ArchiCAD 16 allows performing reliable dynamic energy evaluation of the BIM model.

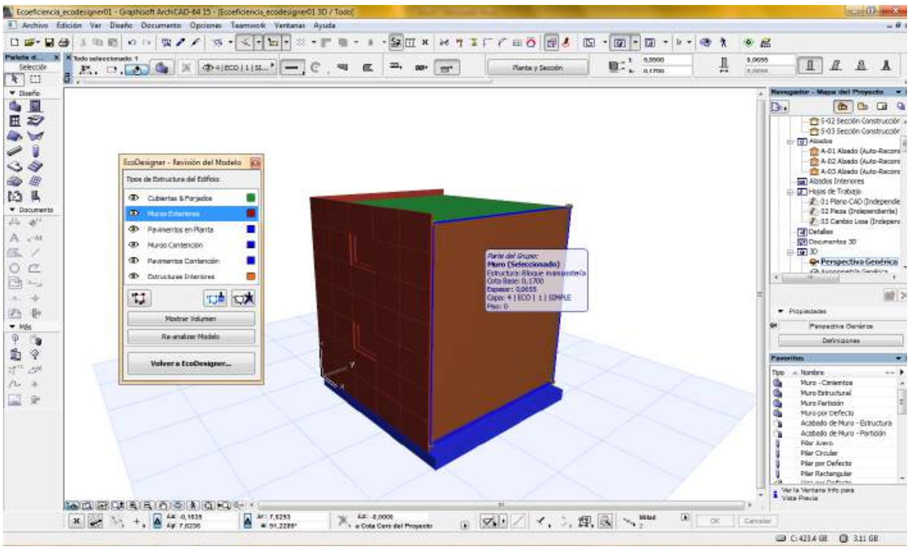


Figure 3: ArchiCAD interface screenshot

[5] http://www.graphisoft.com/products/archicad/

- DDS-CAD[6]: It is a suite of complimentary solutions for the construction industry (available separately or as a single integrated products) allowing the design and documentation of buildings projects. DDS-CAD is a multidisciplinary database supported 3D planning solution, with integrated calculation functionality.

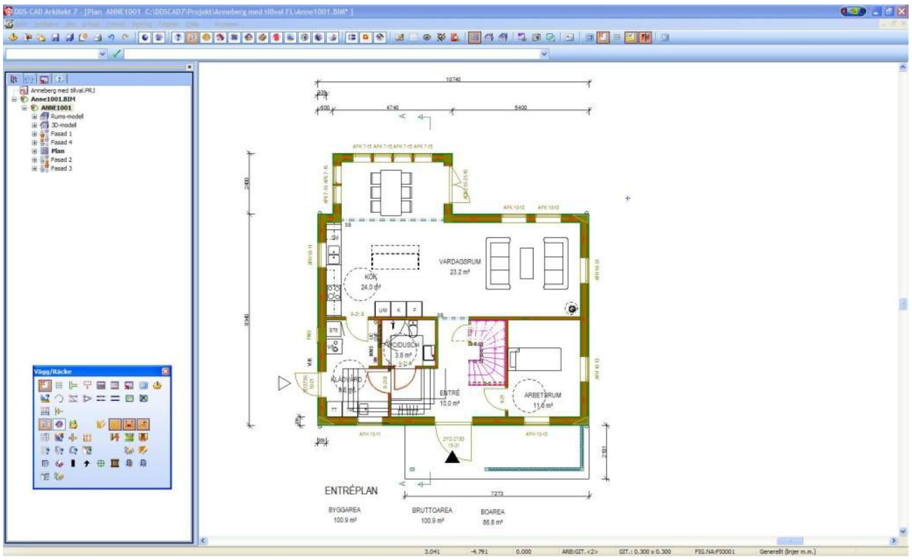


Figure 4: DDS-CAD interface screenshot

1.2 Energy analysis in-built functionalities

1.2.1 Table of functionalities

The following list has been elaborated based on analysis of implementation case studies, review of literature and Acciona's background. It provides an overview of the main functionalities to support energy analysis which are include in some of the BIM tools commercially or freely available in the market. Most of these functions are seamlessly integrated in the tools, making them easy to use.

The chart is divided in 3 columns. The first one lists the BIM tools. The functionalities are listed in the second row, and described in detail in the next section to provide a brief overview for project partners who may not be familiar with BIM use. The last column enumerates the preferred phase to perform that kind of analysis throughout the life cycle of a building design.

[6] http://www.dds-cad.net/ax2x0.xhtml

BIM software tool	Functionality	Phase/s
Revit/Vasari/ArchiCAD	Building energy and carbon analysis	Conceptual and detailed design phase
Revit/Vasari	Solar studies	Conceptual and detailed design phases
Vasari	Solar radiation analysis	Conceptual and detailed design phases
Vasari	Wind analysis	Conceptual and detailed design phases
Revit/Vasari/ArchiCAD	Exchange capabilities	Conceptual and detailed design phases
Revit/ArchiCAD	Certifications support	Conceptual and detailed design phases

Table 1: 'Green BIM' functionalities chart

1.2.2 Detailed description of 'Green BIM' functionalities

1.2.2.1 ENERGY AND CARBON ANALYSIS

The building energy analysis can be performed from the early stages to more advanced and detailed stages. Based on a:

- geometric analysis of the BIM model,
- accurate hour-by-hour weather data of the project location,
- the physical material properties of the element conforming the building
- and building function data (to determine related temperature and heat gain profiles)

The built-in or web-based engine included within the BIM tools (depending on the tool) calculates building energy balance and provides building energy evaluation reports containing information on the project's energy-related structural performance, yearly energy consumption, carbon footprint and monthly energy balance.

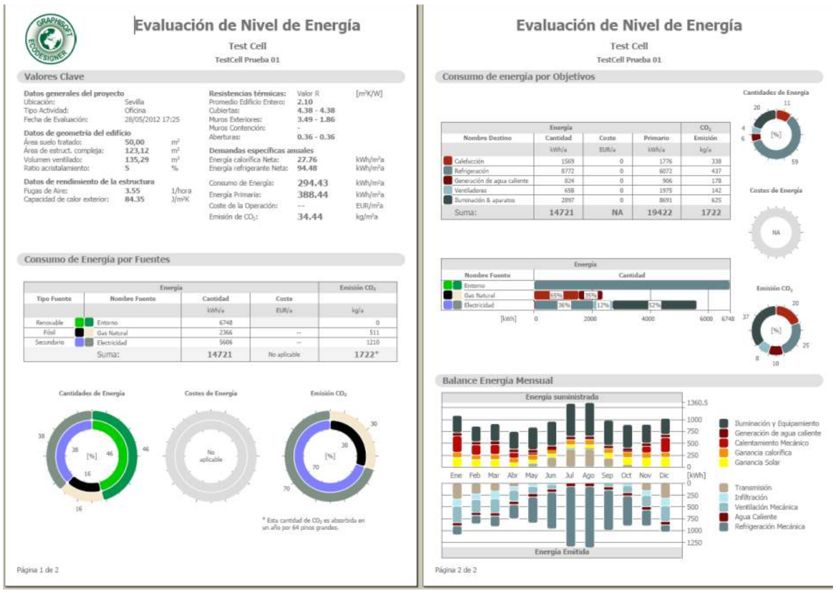


Figure 5: Example of energy evaluation report from ArchiCAD

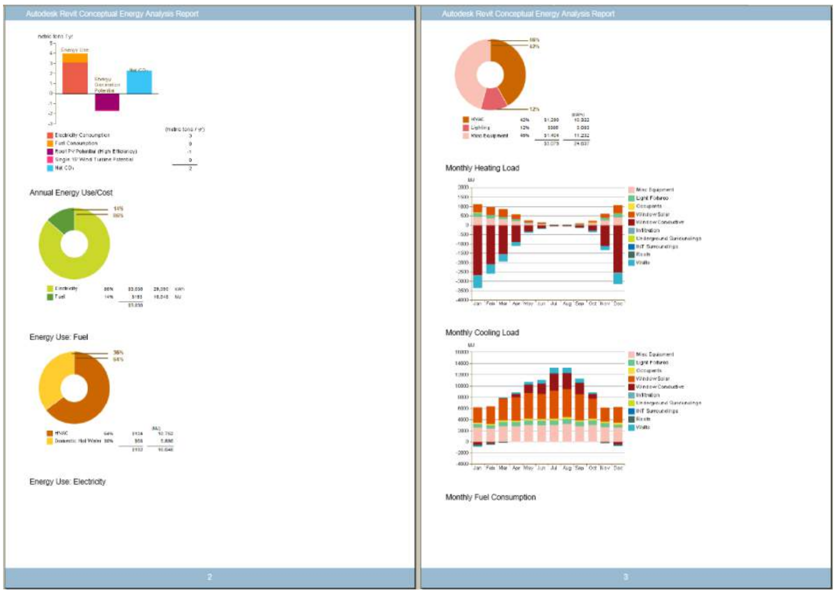


Figure 6: Example of energy evaluation report from Revit and Vasari

The energy analysis can be run from a detailed BIM model but also from a conceptual BIM model built in the very early phases of the design.

The Conceptual Energy Analysis (CEA) involves the automatic conversion of conceptual design BIM models into analytical energy model in order to conduct different energy and carbon analysis and obtain highly visual analysis reports, including energy usage, lifecycle costs, breakdown of consumption and loads.

As an early design concept changes, the energy model and conceptual massing forms are updated accordingly. This makes it possible to continuously conduct energy and carbon analysis and compare design alternatives or 'what if' analysis to provide guidance on which is the best option for optimal energy performance. For instance, massing studies can be used to make decisions about how the building is place on the site.

These integrated very early analyses help make more informed decisions in the conceptual design phase when changes are least time-consuming and expensive. Furthermore, the conceptual model can be used to form the basis of the more advanced model as the design develops.

CEA requires a conceptual BIM model divided into levels, and then the program generates an analytical energy model from the massing model by automatically rationalizing the form into thermal zones and building surfaces; based on some parameters predefined, namely site location, construction type, percentage of glazing, surrounding building (they will be treated as shading devices), building type, hours of operation and HVAC systems.

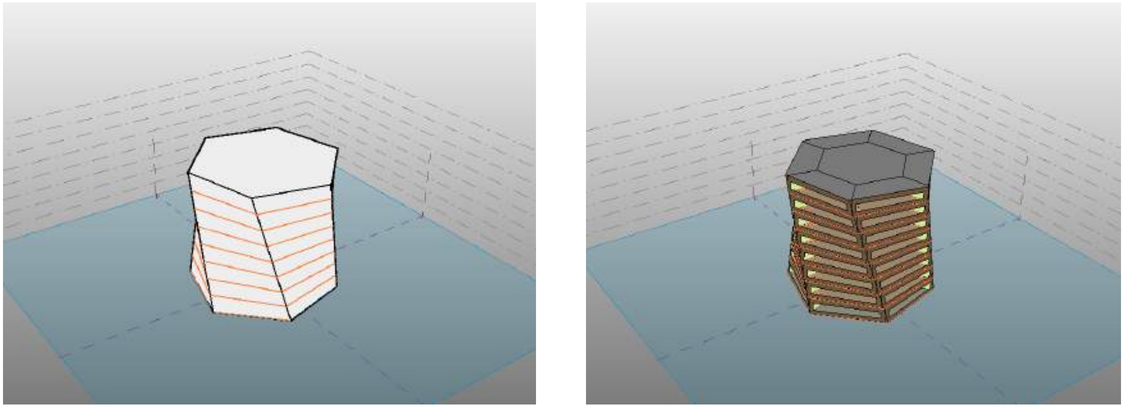


Figure 7: Conceptual mass model and conceptual energy model

This kind of analysis is traditionally performed by more advanced and specific tools like Ecotect or Design Builder, but requires the building to be defined in more detail rather than just a model in the very early phase of the design.

1.2.2.2 SOLAR STUDIES

Evaluation of the impact of natural light and shadows on the design by performing solar studies using BIM tools' sun path functionality, which is a visual representation of the sun's range of movement across the sky at the geographic location specified for the project.

It allows creating solar studies by placing the sun at any point along its daily path, and at any point along its analemma. It is also possible to animate solar studies for a defined period.

Visualization capability included in BIM tools can be used to show light pollution or day lighting analysis through realistic renderings.

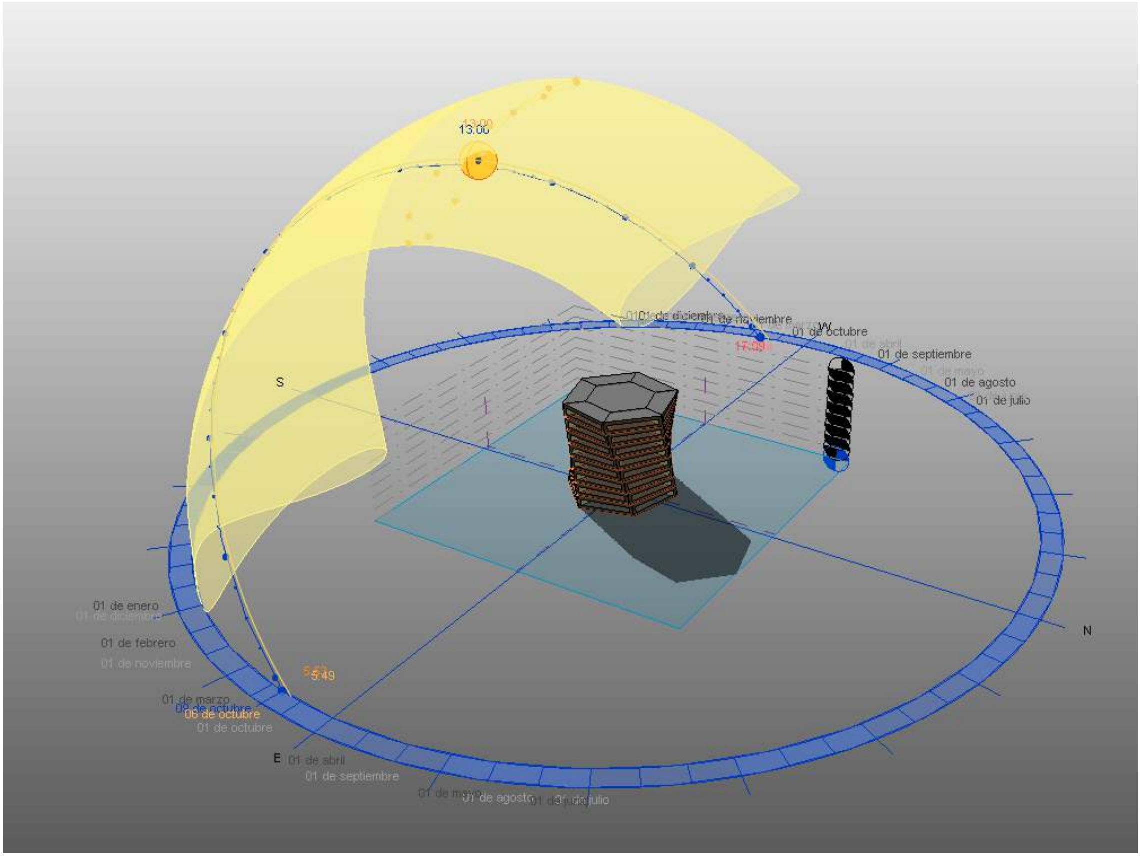


Figure 8: Sun path functionality in Revit and Vasari

1.2.2.3 SOLAR RADIATION ANALYSIS:

This feature enables to study incident solar radiation on a building form within the conceptual massing environment, providing an understanding of the incident solar radiation on a building façade.

The analysis results are presented directly within the context of the model display:

- shadow animations resulting from shadow casting analysis from adjacent objects, such as vegetation and surrounding buildings in an urban setting;

- surface-mapped information such as incident solar radiation, which could help to locate properly photovoltaic panels.

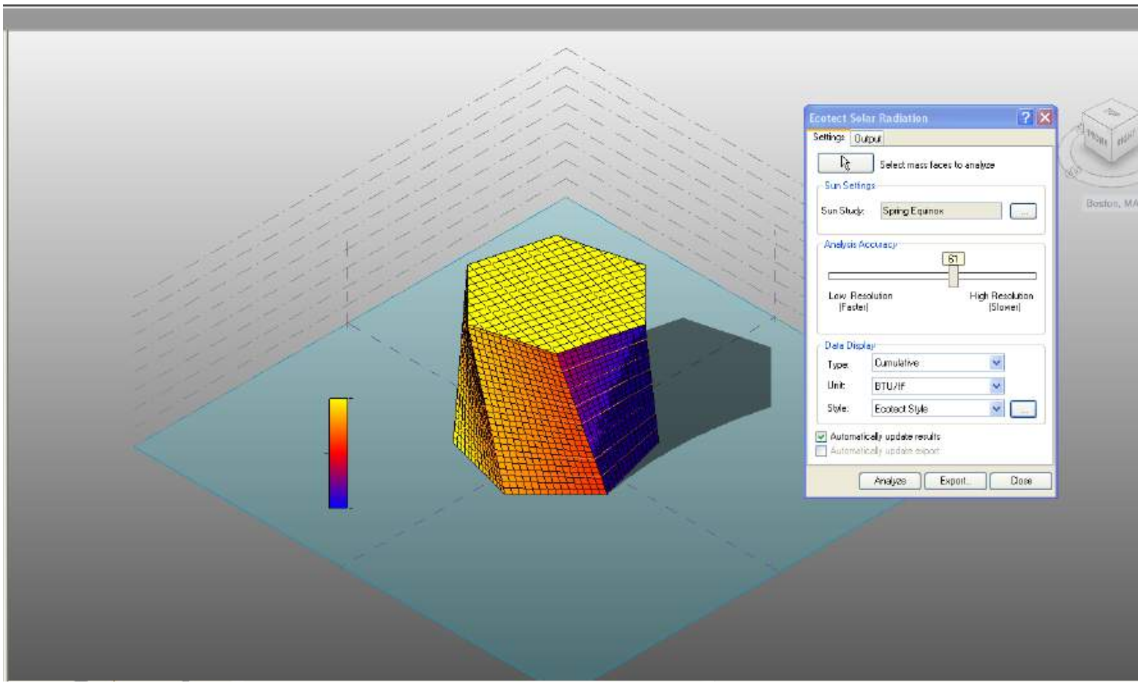


Figure 9: Solar radiation functionality in Vasari

1.2.2.4 WIND ANALYSIS AND AIRFLOW SIMULATION

This feature enables to run computational fluid dynamics (CFD) simulations in order to analyze the potential impact of wind speed and direction on the project. It allows running either 2D or 3D airflow analyses using an interactive grid control and multiple options for displaying the analysis data and how it interacts with the building, visualizing the wind speed and direction data directly in the BIM model for different seasons and time of day. The 2D and 3D visualization provide highly visual understanding of how air will flow across the building and site.

In addition, it provides a dynamical simulation of the impact of wind speed, direction, and relative frequency and 3D simulations of key airflow circulation paths providing designers and engineers a 'virtual wind tunnel' to gain insight on aerodynamic effects early in the design and an indication of the potential impact on pedestrian comfort.

The 'wind rose' functionality displays the speed and direction of prevailing winds at different times of the year with respect to the site and the buildings within it.

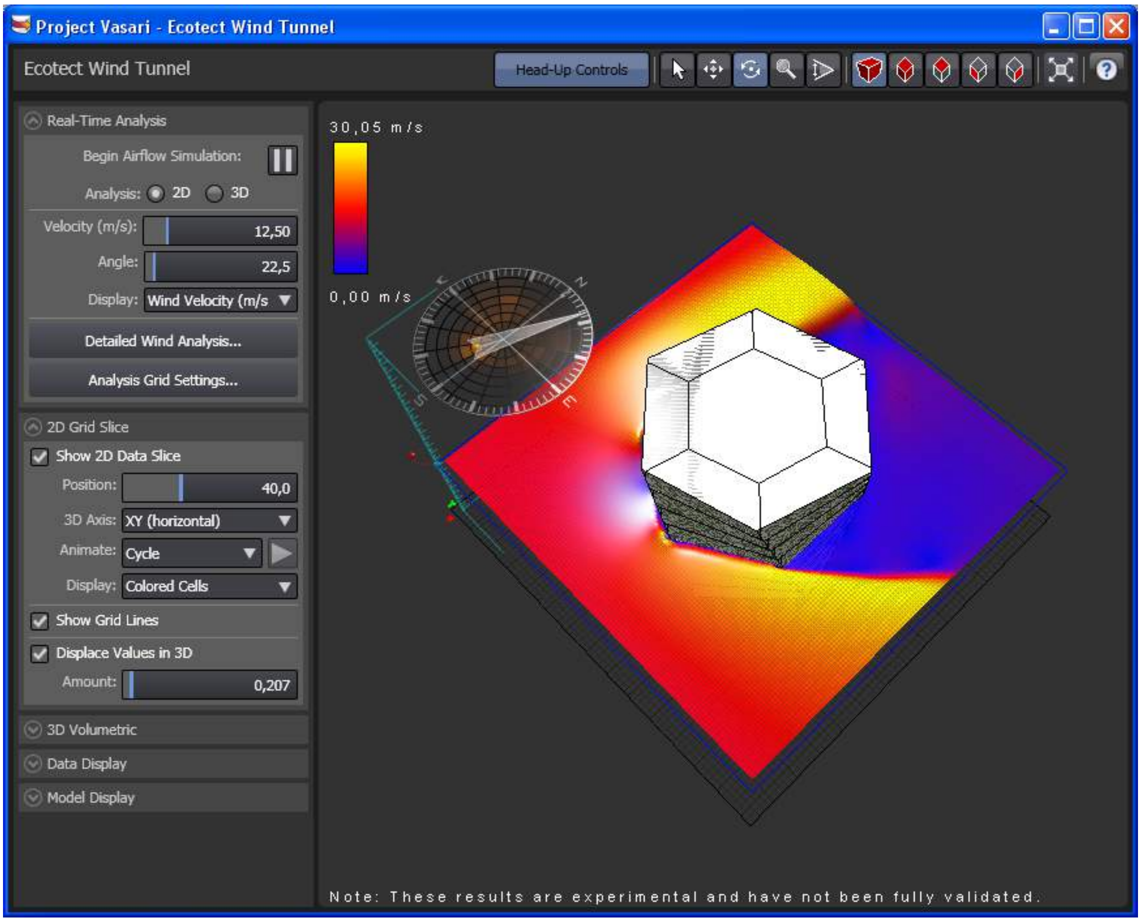


Figure 10: Ecotect wind tunnel functionality in Vasari

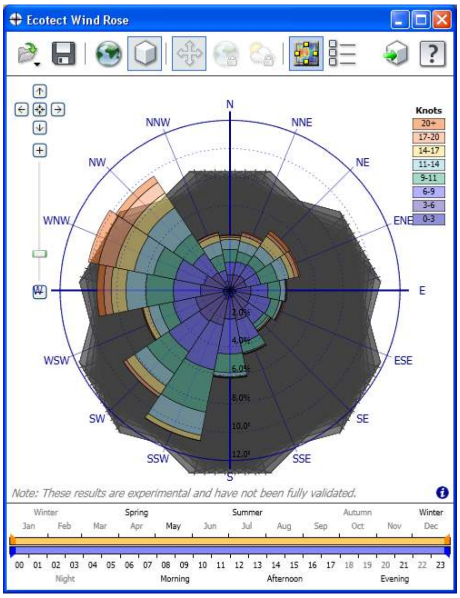


Figure 11 Wind rose functionality in Vasari

1.2.2.5 EXCHANGE CAPABILITIES

BIM tools allow the direct input of building geometry to the analysis tools unlike the traditional workflow where a separate modelling for building performing is required. These tools can export the energy model into standards exchange formats as gbXML, INP (DOE2) and IDF (Energy Plus) formats for further analysis. Besides, the results from the energy analysis can be saved as raw csv, pdf and image files for using and sharing them. GbXML files, intended specifically for storing data relating to energy analysis, can be derived from the conceptual energy analysis BIM model (Revit and Vasari) or more detailed BIM models (Revit, ArchiCAD). It consists of building geometry and thermal zone information (specified space types, interior loads, construction and HVAC equipment data). It can be used in most of the energy analysis software tools to extract the data required for analysis.

1.2.2.6 SUPPORT FOR CERTIFICATIONS (National certifications, LEED, BREEAM…)

BIM tools cannot automatically validate energy certifications; however, BIM as a database is an excellent system for the calculation of requirements for credits that is typical during the life of a project.

Much of the data needed for supporting sustainable design and certifications is captured naturally as design proceeds, so drawings and schedules of building components can be obtained directly from the BIM model to be submitted to support the qualification for the credits.

For example, it is possible to create a schedule in order to calculate the windows area for LEED EQc8.1. When the model has sufficiently been detailed and schedules created, you can easily determine which rooms do and do not the required criteria.

1.3 Mapping of BIM and usual tools

The followings charts show, for every demo-site country, the correspondence between the functionalities allowed by BIM software tools and the usual energy analysis tools. It is based on the NEED4B consortium's experience and knowledge of energy analysis software tools.

Demo-site country: TURKEY (OZU)				
BIM software tool	**Functionality**	**Phase/s**	**Usual software tool**	**Usual phase**
ArchiCAD/ Revit /Vasari	Building energy and carbon analysis	Conceptual and detailed design phases	Carrier 4.3 / Revit DesignBuild er	Conceptual and detailed design phases
Revit/Vasari	Solar studies	Conceptual and detailed design phases	Carrier 4.3 Autodesk Ecotect	Conceptual and detailed design phases
Vasari	Solar radiation analysis	Conceptual and detailed design phases	Carrier 4.3 Autodesk Ecotect	Conceptual and detailed design phases
Vasari	Wind analysis	Conceptual and detailed design phases	Revit Autodesk Ecotect	Conceptual and detailed design phases
Revit/Vasari/A rchiCAD	Exchange capabilities	Conceptual and detailed design phases	Autocad - Revit DesignBuild er	Conceptual and detailed design phases
Revit/ArchiCA D	Certifications support	Conceptual and detailed design phases	Carrier 4.3 / Revit DesignBuild er	Conceptual and detailed design phases

Table 2: BIM and usual functionalities mapping chart

Demo-site country: ITALY (DAPPO)				
BIM software tool	**Functionality**	**Phase/s**	**Usual software tool**	**Usual phase**
ArchiCAD/ Revit /Vasari	Building energy and carbon analysis	Conceptual and detailed design phases	Excel spreadsheet and or Building Energy Rating Certification software tools provided by certification bodies	Conceptual and detailed design phases
Revit/Vasari	Solar studies	Conceptual and detailed design phases	Manual or tool driven SOLAR-CHART for shadow calculation - Also Google SketchUp	Conceptual and detailed design phases
Vasari	Solar radiation analysis	Conceptual and detailed design phases	Tools from solar panels manufacturers/providers	Conceptual and detailed design phases
Vasari	Wind analysis	Conceptual and detailed design phases	Manually assessed / excel spreadsheet	Conceptual and detailed design phases
Revit/Vasari/ArchiCAD	Exchange capabilities	Conceptual and detailed design phases	Manually assessed / excel spreadsheet	Conceptual and detailed design phases
Revit/ArchiCAD	Certifications support	Conceptual and detailed design phases	Building Energy Rating Certification software tools provided by certification bodies.	Conceptual and detailed design phases

Table 3: BIM and usual functionalities mapping chart

Demo-site country: SPAIN (ACCIONA) (Tools used are market in bold)				
BIM software tool	**Functionality**	**Phase/s**	**Usual software tool**	**Usual phase**
ArchiCAD/ Revit /Vasari	Building energy and carbon analysis	Conceptual and detailed design phases	**Energy+,** TAS, IES VE, EQUEST	Conceptual and detailed design phases
Revit/Vasari	Solar studies	Conceptual and detailed design phases	**DB**, Ecotec, TAS, IES VE Radiance	Conceptual and detailed design phases
Vasari	Solar radiation analysis	Conceptual and detailed design phases	**DB**, Ecotec, TAS, IES VE Radiance	Conceptual and detailed design phases
Vasari	Wind analysis	Conceptual and detailed design phases	**DB**, IES VE	Conceptual and detailed design phases
Revit/Vasari/ ArchiCAD	Exchange capabilities	Conceptual and detailed design phases	Revit ↔IES VE **E+** ↔ TAS	Conceptual and detailed design phases
Revit/ArchiCAD	Certifications support	Conceptual and detailed design phases	**DB**, IES VE , CALENER	Conceptual and detailed design phases

Table 4: BIM and usual functionalities mapping chart

Demo-site country: BELGIUM (F2D)				
BIM software tool	**Functionality**	**Phase/s**	**Usual software tool**	**Usual phase**
ArchiCAD/ Revit /Vasari	Building energy and carbon analysis	Conceptual and detailed design phases	Software PEB (National software) : energy analysis + PHPP (passive analysis)	
Revit/Vasari	Solar studies	Conceptual and detailed design phases	Never used	

Vasari	Solar radiation analysis	Conceptual and detailed design phases	Never used	
Vasari	Wind analysis	Conceptual and detailed design phases	Never used	
Revit/Vasari/ArchiCAD	Exchange capabilities	Conceptual and detailed design phases	ACAD LT	Conceptual and detailed design phases
Revit/ArchiCAD	Certifications support	Conceptual and detailed design phases	Never used	

Table 5: BIM and usual functionalities mapping chart

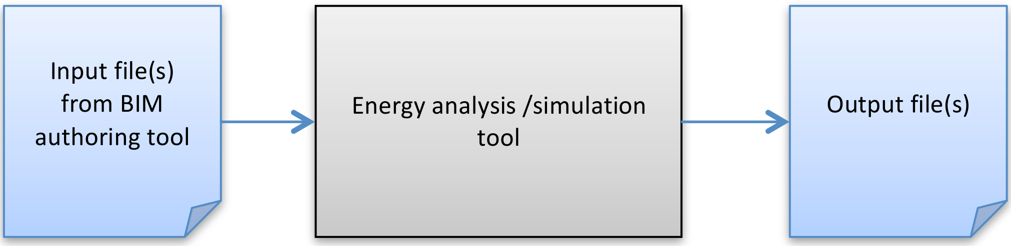
Demo-site country: SWEDEN(DEROME) (Tools used are market in bold)				
BIM software tool	**Functionality**	**Phase/s**	**Usual software tool**	**Usual phase**
ArchiCAD/ Revit /Vasari	Building energy and carbon analysis	Conceptual and detailed design phases	DDS-CAD TMF Energy	Detail design phases
Revit/Vasari	Solar studies	Conceptual and detailed design phases	Never used	
Vasari	Solar radiation analysis	Conceptual and detailed design phases	Never used	
Vasari	Wind analysis	Conceptual and detailed design phases	Never used	
Revit/Vasari/ArchiCAD	Exchange capabilities	Conceptual and detailed design phases	Never used	
Revit/ArchiCAD	Certifications support	Conceptual and detailed design phases	Never used	

Table 6: BIM and usual functionalities mapping chart

2 BIM data exchange for energy analysis

2.1 Information exchange process

The information exchange operation adheres to the following process: a BIM of the building is exported from a BIM-authoring tool in the file format required by the simulation application. The energy simulation tool uses this input file which contains a representation of the data needed, additional inputs and assumptions are entered by the energy modeler to complete the required input process. Based on those inputs, the engine performs a simulation and writes its output in one or more output files.



- Information exchange process diagram -

By leveraging the import of the building geometry into the energy simulation program, significant time savings are realized by not having to recreate the geometry from scratch.

Depending on the analysis tool used, a BIM-based energy model can require the introduction of different parameters. The level of detail of BIM models depends on the scope and level of detail of energy analysis to be performed and it could differ also depending on the application used. This information may include geometric data, construction types/materials and their associated thermal properties, space loads, as well as other useful simulation parameters. Therefore, a process should be adopted in order to ensure suitability and accuracy of the information transfer to the energy model using BIM. The tests developed during this task will serve to define this standard methodology to create and transfer successfully a building information modeling to energy calculation software.

2.2 Current data schemas for Building Information exchange

2.2.1 IFC

Industry Foundation Classes (IFC) is the open and international standard for exchanging BIM data. It is a task and schema specification that provides standard ways to define information contained in BIM. IFC is an object-oriented data model developed by the BuildingSMART International association (former International Alliance for Interoperability -IAI-) used to describe the relationships and properties of building specific objects. IFC format is non-proprietary and is available globally to anyone.

A building information model is an integrated database of a building or facility. IFC format describes the behavior, relationship, and identity of a component object within that model. IFC format does not standardize data structures in software applications, only the shared information. IFC provides a framework for organizations to produce interoperable software in order to exchange information on building objects and processes, and creates a language that can be shared among the building disciplines, with discipline-specific views specified through Model View Definitions (MVD) and at times, implementer agreements. Most BIM-authoring vendors[7] are currently compliant with the Coordination View, with partial implementations towards other MVDs.

2.2.2 XML

Extensible Markup Language (XML) is a task and schema specification that provides standard ways to define information like that contained in BIM. XML is a set of rules for designing text formats to structure information. It is an outgrowth of the popular HTML code used to develop Web pages and sites. XML supports data transaction between different software applications, leading to a better way to communicate information.

Several industry-specific sets of rules of XML-based schemas are currently being developed for the AEC industry including green building XML (gbXML), ifcXML, and aecXML. gbXML and ifcXML are the most relevant to building performance analysis, with gbXML being by far the most common.

2.2.2.1 gbXML

gbXML, or the Green Building XML schema, allows for a detailed description of a single building or a set of buildings for the purposes of energy and resource analysis. It allows for consistent data interoperability between BIM applications and energy simulations programs.

This format is designed to transfer essential information as walls, windows and room areas, excluding superfluous items of the building information model for energy analysis, such as furniture, stairs, and appliances. Its focus is the data exchange between 3D geometry and energy simulation tools.

GbXML is the most widely supported data format for the exchange of building information between BIM/CAD and energy performance applications[8].

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[7] BIM-authoring tools and vendors with current IFC support (to varying degrees) are listed at http://buildingsmart-tech.org/implementation/implementations.

[8] BIM-authoring tools and vendors with gbXML support (to varying degrees) are listed at http://www.gbxml.org/software.php.

2.2.2.2 ifcXML

ifcXML specification provides an XML schema specification that is a conversion of the EXPRESS (ISO 10303 part 1) representation of the IFC schema. This specification targets the XML community by providing guidelines on using and implementing the IFC standard using XML technologies.

3 Proofs of concept

3.1 Definition and scope

A proof of concept is a realization of a certain method or idea(s) to demonstrate its feasibility, or a demonstration in principle, whose purpose is to verify that some concept or theory has the potential of being used. A proof-of-concept is usually small and may or may not be complete.

To determine the BIM software to be tested in the proofs of concept carried out in task 2.3, in addition to the results from task 1.3[9], a specific query about BIM tools was responded by every demo site coordinator. The next table shows the responses.

DEMO SITE COUNTRY	MAIN BIM SOFTWARE used or to be used
Turkey	Autodesk Revit
Spain	Autodesk Revit
Italy	Autodesk Revit
Sweden	DDS-CAD
Belgium	Autodesk Revit

Table 7: BIM software by demosite

Despite of the diversity of energy calculation software, as far as BIM is concerned, the number of tools to be used by the consortium is reduced. Therefore, the proofs of concepts will focus on Autodesk Revit and DDS-CAD.

It consists of two different types of tests:

a) Tests to evaluate the energy analysis in-built functionalities which BIM tools can carry out (defined in task 2.3a).

b) Tests to evaluate how accurate are the exchange files exported from BIM tools. To do that, a basic model will be exported to IFC and/or gbXML formats. Then these files will be imported in a more advanced energy calculation program. Finally, it will be checked what data have been well exported.

[9] See Appendix A: Summary of software surveys carried out in Task 1.3

Both proofs require the development of a building information model as the basis for the in-built tests and the exchange process. BIM software allows two different approaches to build this model:

- Bottom-up approach or traditional modeling = to create the building on an element by element basis
- Top-down approach or conceptual modeling = the building's overall shape is first defined, and then building elements, such as walls, floors, roof… are applied to either interior or exterior surfaces…

For the in-built functionalities tests only the conceptual modeling has been implemented. For the interoperability tests the two approaches have been utilized.

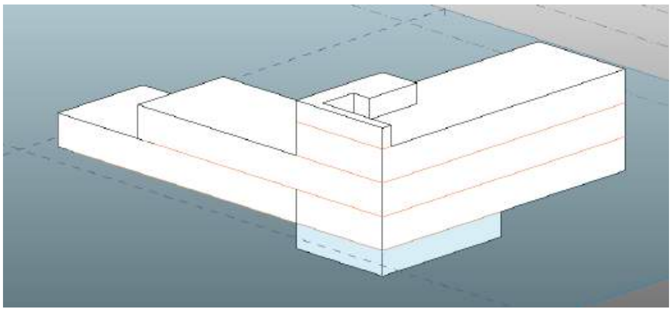

Figure 12: Conceptual modeling

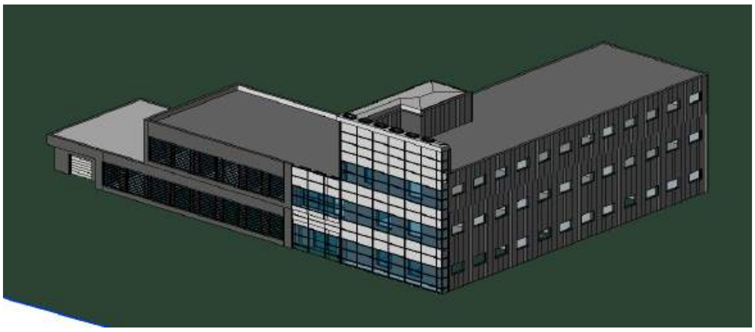

Figure 13: Traditional modeling

3.2 In-built functionalities tests

This tests aim to evaluate the usability of the energy analysis functionalities included in the chosen BIM authoring tools: Vasari/Revit. These tools share the energy calculation engine and both use a conceptual BIM to carry out the analysis.

Sections below describe the method followed during the tests.

3.2.1 Building geometry creation

As explained above, a BIM conceptual models have been created based on a previous and schematic design of Spanish demo site.

The conceptual modeling consists in representing the building as some masses (simple volumes) divided in floors (levels). Exterior surfaces and openings are automatically added to the model based on area specific window provisions (a percentage which represents the surface area of the windows in relation to the floor area or the outside wall area).

Developing this kind of modeling is easy and quick, so changes are not time-consuming and different design alternatives can be analyzed to support the making decisions process. For instance, the two pictures below show different scenarios of the building envelope: large windows surface on the bottom and small windows size on the top.

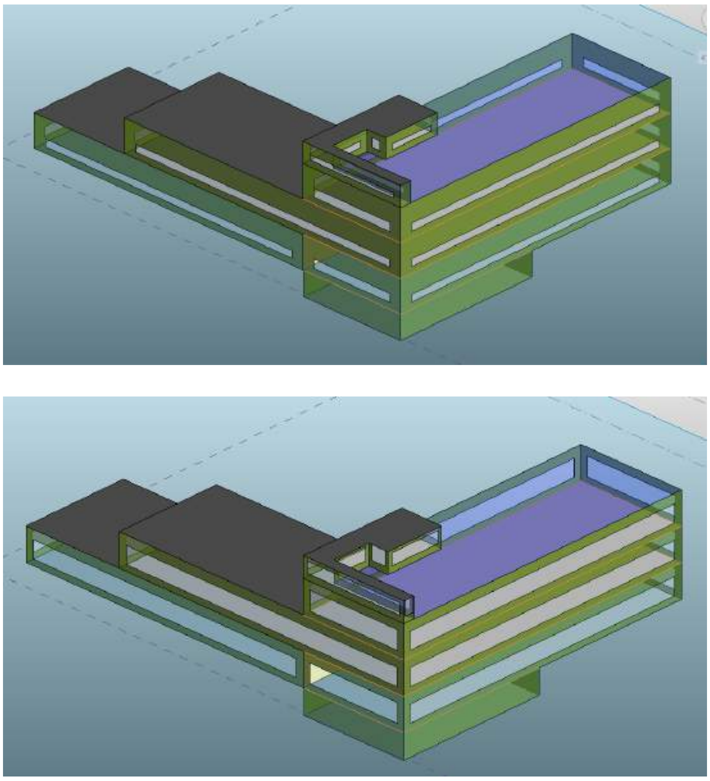

Figure 14: Different openings scenarios

Construction systems and materials which make up the building are selected from a predefined list according to their density, heat capacity and R-value (approximate values).

3.2.2 Data insertion

The next step, following the modeling, is to set the conditions (data) necessary to properly represent the environment both inside and outside of the building. Depending on the stage of design, some of the data introduced can be agreed solutions and other data can be assumptions, that is to say, variable data to test different alternatives and support decisions making.

A complete list of data to be introduced in Revit/Vasari model, both necessary and suitable, is included in Appendix B.

Specific data to include in a BIM from an energy efficient design perspective consists of:

A) Location and climate: The location determines environmental conditions such as outdoor air temperature and humidity and also ASHRAE climate zone data. It can be determined based on the site geographical coordinates since BIM tools have a search engine to download data in CSV (spreadsheet) or BIN (DOE-2 binary) format from weather stations located throughout the world. Climate data used in the calculation are:

- Wind direction
- Wind speed
- Diffuse solar radiation
- Direct solar radiation
- Relative humidity
- Air temperature

Together with the location is important to set the appropriate orientation of the building, as this data has great incidence in energy calculation.

B) Envelope: Data regarding building's envelope can be alphanumerically introduced rather than graphically modeled. Due to this, changes are less time consuming. They include:

- Insulation
- % glazing
- Glazing type
- Shading

C) Use and function: Data regarding the building's usage and typology can be selected and includes:

- Building or space type: typical scheduling of the building based on usage per the whole building or per space.
- Occupancy and schedules: occupancy assumptions for different building operating schedules based on ASHRAE standards.

D) Systems: Information about HVAC, lighting and equipment to be installed in the building.

3.2.3 Energy analysis functionalities

Following the model development and the data insertion, next step is to analyze the model inside the BIM-authoring tool. Different kind of analyses, as described in 2.3a, can be performed with distinct potential applications:

A) Energy and carbon analysis:

This analysis is performed during the early design phase. It provides early estimates for conceptual building information models before any detailed modeling occurs. The usability during design phase of this kind of analysis is:

- To understand of how the model created responds to site and climatic environment.

- To explore different material and shading options to attain the lowest energy use. This iterative results comparison allow to see how explicit changes in the design, whether a material change, a form change, or something completely different, can influence the cost, energy consumption or metrics of the project.

Results obtained in this analysis are explained in detail in next section. These results can be exported as a pdf report and as usual exchange files (gbXML, DOE2 and Energy Plus).

B) Solar studies:

A preliminary solar study can be performed with the sun path tool. The sun path is a visual representation of the sun's range of movement across the sky at the geographic location of the project. The sun can be placed at any point along its daily or yearly path. The applications during design phase of this kind of analysis are:

- To visualize solar shadows and their change over time in order to rightly orient the building sensitive to the solar path and the shading.

- To preview and export a solar path animation (as images or videos) to be used later in presentations to the owner, end users…

- To study of the shade depth for all orientations on specific dates as Summer Solstice, Winter Solstice, Autumn Equinox, and Spring Equinox.

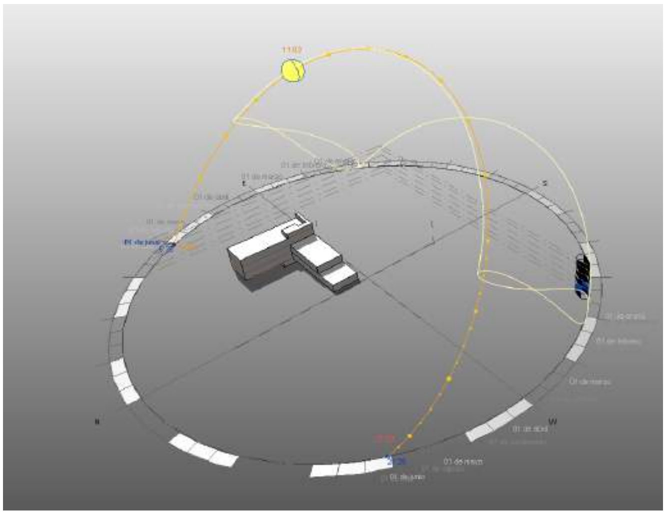

Figure 15: Solar sun path

In addition, it is possible to perform solar radiation studies. This feature visualizes the distribution of solar radiation on various areas of a mass by taking into account the shading effects from adjacent objects, such as vegetation and surrounding buildings in an urban setting. The applications during design phase of this kind of analysis are:

- To figure out where solar heat gain is most extreme and the best way to mitigate it, whether it is changing orientation or adding shading to the exterior.
- To show solar heating load incident to the envelope of the building and understand how the building form is impacted by the sun
- To export a .csv file of the results as input data for more advanced energy analysis tool.

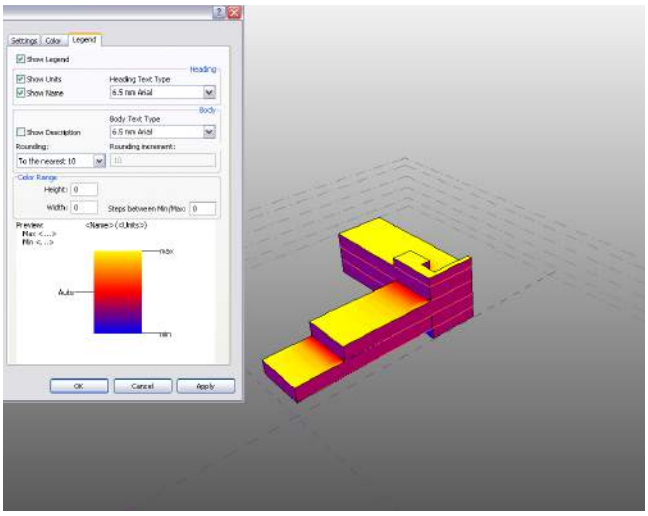

Figure 16: Solar radiation study

D) <u>Wind analysis and airflow simulations</u>:

The applications during design phase of the wind analysis are:

- To study local wind conditions based on data from the weather station.
- To visualize the prevailing wind patterns for the site. It is possible to limit the analysis period by year, season, month, week or day.

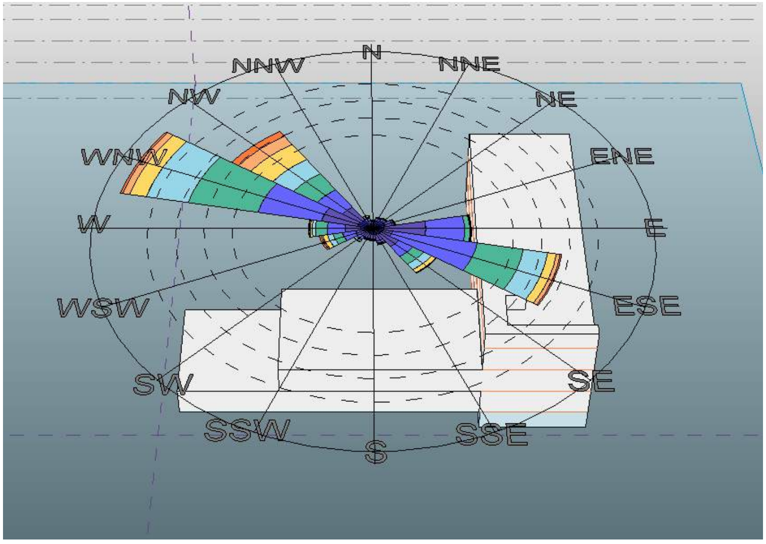

Figure 17: Wind rose diagram showing velocity, direction and frequency

Furthermore, the wind tunnel analysis allows dynamically simulating the impact of wind speed and direction on the building. It provides a simplified computational fluid dynamics simulation that provides designers with a virtual wind tunnel to gain an insight on aerodynamic effects early in the design process. Main uses for this tool are:

- 2D and 3D exterior air flow to provide a highly visual understanding of how air will flow across the building and the site.
- 3D simulations if key airflow circulation paths to provide an indication of the potential impact on pedestrian comfort.
- 3D simulations of air flow across buildings to estimate the external pressure envelope.
- Preliminary wind loading calculations

Because this process happens in real-time as an interactive file, it is an opportunity to add site elements and modify the building form and orientation to see the immediate impact on wind conditions.

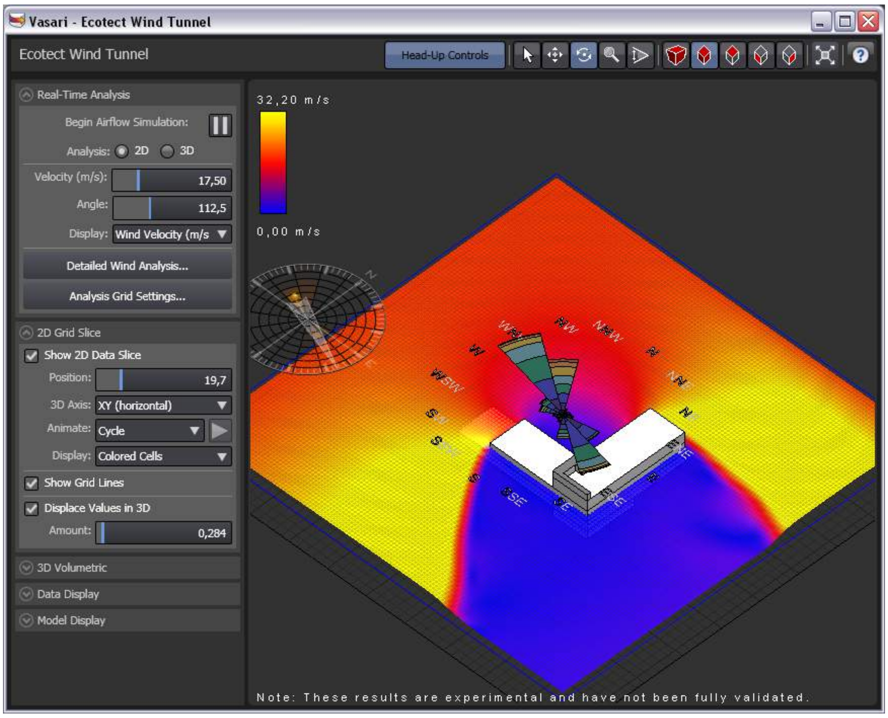

Figure 18: Wind tunnel analysis

3.2.4 Energy analysis results

Energy and carbon analysis carried out in BIM applications provide a result sheet which consists of the following tables and graphs:

- Building performance factors table which summarizes the major factors that affect the energy consumption of the analyzed model. The floor area corresponds to the gross floor area of the analyzed model. The average lighting power is the building-wide average of watts of lighting electricity per area of conditioned indoor space. The exteriors windows ratio corresponds to the ratio of window area to gross wall area.

- Energy Use Intensity table which represents the energy consumed by a building relative to its size (it is a per-floor-area unit of measurement). The data for electricity focus on electricity required to run the building. The value for fuel represents the total amount of raw fuel that is required to operate the building. The Total value sums fuel and electricity and incorporates all transmission, delivery, and production losses, thereby enabling a complete assessment of energy efficiency.

- Life cycle energy use/cost table which summarizes the estimated energy usage and cost over the life of the building, assuming a 30-year life span.

- Renewable energy potential table which represents the amount of electricity that the building site could produce using solar panels and wind turbines. These analyses are based on data from the climate file. All roof surfaces on the building are analyzed in order to estimate the potential to generate electricity using photovoltaic panels. Wind energy potential is estimated based on the annual amount of electricity that can be generated from one 4.5meters-diameter wind turbine of horizontal axis design. The estimate uses cut-in and cut-out winds of 6 and 45 miles per hour respectively, located at the coordinates of the weather data.

- Annual carbon emissions graphs which summarize the estimated CO2 emissions associated with energy consumption for the analyzed model. Graphs illustrate the following equation:

  Energy Use CO2 – Energy Generation Potential CO2 = Net CO2,

  where *Energy Use CO2* is the estimated annual CO2 emissions for electricity and fuel consumption for the analyzed model and *Energy Generation Potential* (negative number) represents tons of carbon you can potentially remove from the project by using renewable energy rather than obtaining power from the electricity grid.

  To calculate CO2 emissions for projects outside the U.S.A., Carbon Monitoring for Action (CARMA) data is used.

- Annual energy use/cost chart which compares estimated energy use for major fuel versus electricity. Major fuels include heating, oil, natural gas, propane, and other resources. The percentage break-down is based on usage (using a common unit of kBtu, 1 therm=100 kBtu, 1 kWh = 3.413 kBtu), not costs.

- Annual fuel use chart which compares estimated fuel use for HVAC (heating, ventilation, and air conditioning) and domestic hot water usage (1 therm = 100 kBtu = 105.5 MJ). Major fuels include heating oil, natural gas, propane, and other resources. It shows the percentage of total fuel use, costs, and therms for each end use.

- Annual electricity use chart which shows estimated electricity use for major end uses, including HVAC, lighting, and equipment. Equipment includes computers, lifts, and miscellaneous appliances. For each end use, it shows the percentage of total electricity usage, costs, and kilowatt-hours (1.0 kWh = 3.6 MJ = 3413 BTU).

- Monthly heating and cooling loads graphs which shows the cumulative heating and coaling loads on the analyzed model for each month.
  These charts do not represent the peak load used for sizing of heating equipment. It also does not represent loads caused by ventilation air, which can have a significant impact in densely occupied buildings.
  In the cooling chart, positive values represent cooling demands that must be satisfied by a cooling system or other means and negative values offset the need for cooling.

- Monthly fuel and electricity consumption graphs which display the project's estimated fuel and electricity usage by months.

- Monthly peak demand graph which displays the project's estimated peak electricity demand (maximum instantaneous electrical load) by month.

- Annual wind rose that provides a graphical display of wind speed and direction data, using 16 cardinal directions. The speed distribution chart shows the frequency and speed of wind blowing from each direction. The frequency distribution chart shows the same data as the speed distribution, except the radial scale that represents wind speed rather than percent of time.

- Monthly wind roses graphics which shows frequency distribution for each month of the year.

- Monthly design data chart that provides data about outdoor design conditions: the outdoor dry-bulb temperature used to calculate cooling and heating loads; the average daily minimum and maximum dry-bulb temperatures for each month and the average of all hourly dry-bulb temperatures for the month.

- Annual Temperature bins chart which displays the number of hours per year that dry-bulb and wet-bulb temperatures fall within a certain temperature range (temperature bin).

- Diurnal weather averages chart which tracks annual averages for temperature and solar radiation. The y-axis on the left is the temperature, and the y-axis on the right is the solar radiation in BTUs per hour per area.

- Humidity chart which shows the annual range of relative humidity. Because the humidity can vary greatly throughout the course of one day, and is typically higher in the mornings, the chart shows the morning average and the afternoon average. The mean daily range is the difference between the averages of the daily maximum and minimum relative humidity for the month. The full range is a record of the absolute maximum and minimum relative humidity for the month.

In Appendix C, it is included the result charts of one of the tests performed as part of the proof of concept with Vasari.

3.3 Exchange tests

These tests aim to research how building geometry, elements, and properties should be inserted in BIM to ensure an effective transfer of information to the energy simulation programs.

It is important to note that the BIM-based energy analysis process currently involves emerging products and technologies, and limitations in the process of transferring information from BIM to energy simulation programs do exist. Therefore, it is important to find out which required data could be contained within the BIM model and convey to energy calculation tools.

Due to the wide range of BIM software currently commercialized, there is a large variety of flows suitable between BIM tools and energy analysis tools. For the proof of concept regarding interoperability, next flows have been selected:

- Conceptual model from Vasari/Revit to Design Builder through gbXML schema
- Conceptual model from Vasari/Revit to Green Building Studio through gbXML schema
- DDS-Cad to VIP Plus through IFC schema

3.3.1 Exchange through gbXML

A lot of the information that energy analysis software needs afterwards is already included into the building information model. Spaces (type, area and volume), surfaces (including adjacency and thermal properties) and shading are part of the gbXML schema.

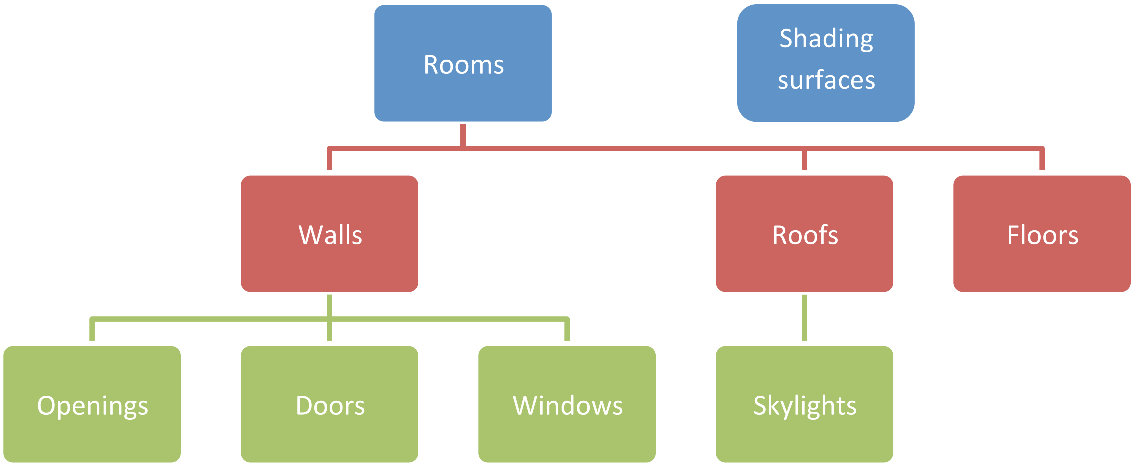

Figure 19: gbXML schema hierarchy

The above diagram depicts the hierarchy of a standard gbXML format. Rooms are the holder of most of the parameters passed from BIM software into analysis software. Shading surfaces are generated when bounding elements in the BIM physical model do not actually bound any rooms.

The exported gbXML file contains all of the heating and cooling information for a project according to the gbXML file structure. However, when a building information model is exported to an analysis program with gbXML, none of the geometry of the building is exported, only the room data, which understands what it is touching. By using the space boundaries of the BIM, the energy analysis program can interpret common situations such as where a roof is shared by a cold external area and a heated area.

The method followed during the test has been to create two models with two different levels of detail (conceptual and detailed) and exported as gbXML files. The following step has been to import these gbXML files into Design Builder and Green Building Studio to perform a usual energy analysis. The building selected for the proof has been an early design of the building from the Spanish demo site.

Once the gbXML file is imported, some verification has been undertaken:

- If spaces are properly defined using correct wall space boundaries (e.g. inner face vs. wall centerline) and the correct height (e.g. up to ceiling surface vs. overlapping ceiling surface).

- If all spaces are assigned to a Thermal Zone object, all the Thermal Zones are assigned to an HVAC Zone, and all HVAC Zones are assigned an HVAC equipment type (if conditioned). This could facilitate the correct assignment of systems to spaces once imported in the energy model.

- If the appropriate construction material data, such as thermal conductivity, thermal mass properties, and surface finish properties, etc. is assigned to room bounding surfaces.

- If lighting and equipment loads, occupant loads, indoor requirements (heated, cooled, heated and cooled, unconditioned), conditioning schedules (e.g. hours per day on/off), design space temperatures, outside air requirements, infiltration rates, and lighting, equipment and occupant schedules are included into the gbXML file.

- If space-bounding surfaces have been designated as adiabatic (heat transfer exists) or non-adiabatic (no heat transfer exists).

In order to find out how well properties included in the BIM are exported through the gbXML file, an exported properties checklist was developed. It is displays in Appendix D.

3.3.2 Exchange through IFC

The method followed during the test has been to create a model into DDS-CAD and exported directly to Norwegian and Swedish energy calculation software and as an IFC file in order to test the usability of IFC with energy software. The building selected for the proof has been a house similar to those to be constructed in the Swedish demo site.

Regarding the interoperability between DDS-CAD and the specific Nordic software, these are the conclusions:

- Vital information may be missing, as instance U values and glass areas and shading information.

- The BIM may be correct regarding to how to build, but the energy calculation may need information that is not present in a BIM even if it is correctly defined or modeled. For example wall and floor areas needed for energy calculation will not be the same as the «real» wall and floor areas. The same goes for floor at the lowest storey: Floor is normally modeled as built, but «energy» floor is calculated inside of external walls, which is not the «real» floor.

- Only parts of objects must be used for energy calculation, e.g. roof. Roof surfaces are normally modeled as the exterior part of the roof which will be the «roof tile area» – not the «energy area».

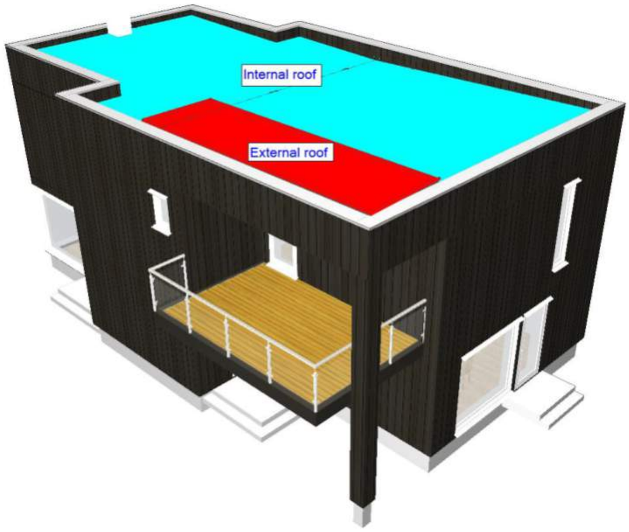

Figure 20

- A correct modelled BIM will have wall layers as shown in the figure below. In this case we will be missing some internal wall areas.

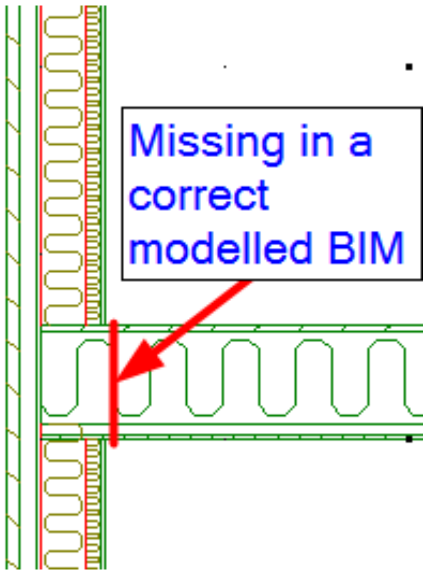

Figure 21

- DDS-CAD Architect automatically calculates all the necessary input to the Norwegian Excel based energy calculation tool TEK-sjekk and this will be the same for TMF Energy for the Swedish market.

- All areas are adjusted automatically for the energy export according to Norwegian rules/standards. The BIM itself is kept «correct»:
  - Wall areas are adjusted to be including floor thickness

– Floor areas are adjusted to be inside of external walls
– Roof areas are adjusted to be inside of external walls

- All walls, windows and doors get their shading information automatically calculated. Any obstacles like other walls, roof overhang, window framing, etc that make up a part of the shading will be considered and formatted into the TEK-sjekk format for how to handle input of these values. Each object calculates shadings above and to each side. Even horizon is automatically calculated if you have surrounding building(s) added or a terrain model included. The following images show as each «ray» will be transferred into information about distances to the obstacles

Figure 22

Vegg 18	Yttervegg mot friluft	S (180°)	14,13			10°	0+0,00;2,10/5,11+0,01;0
				Dør type 2	1,89	10°	0+0,30;2,10/1,15+0,25;0
				Vindu type 1	0,40	10°	;2,19/3,76+3,26;0,08/0,48+0,00

Figure 23

Appendix E resumes the specific test carried out to evaluate the connection and information exchange between DDS-CAD and TEK.

Regarding the usability of IFC with energy software, tests with the IFC model (from DDS) and other BIM software (ArchiCAD and Revit) were not as fine as expected.

The IFC model appears incomplete when it is imported in other software and it needs a lot of 'rework' to achieve a proper definition level. This is due to the fact that to achieve a fine IFC model, it has to be previously modeled according to specified requirements. The definition of those requirements is out of the NEED4B scope.

3.4 Conclusions

3.4.1 Energy analysis based on conceptual building information models

One of the advantages of BIM-based energy analysis is the quickly feedback obtained. Using this kind of analysis early in the conceptual design phase can facilitate more informed design decisions before entering detailed design. Some of the benefits are clear: designers can determine how to orient a building with idealized solar exposure, how to mitigate energy use, how to select and pursue one design option over another, as well as easily track and document the changes that occur through this design process. By identifying the end use that requires the most fuel, designers can focus on strategies to reduce overall energy consumption for the project. In the same way, by understanding the end use that requires the most electricity, designers can focus on strategies to reduce overall energy consumption for the project. By studying the wind patterns for a location, designers can make informed decisions about natural ventilation strategies, locating wind turbines appropriately, and shielding buildings from cold winter winds.

The possibility of performing an iterative analysis is another major advantage. As conceptual energy analysis is a basic process, it can and should be used multiple times at different stages during the design process.

In conclusion, energy modeling tools within BIM applications that assume internal loads, schedules, and systems for early conceptual models can identify qualitative benefits of architectural options but cannot quantify them accurately in terms of energy usage and cost without refinement of the MEP systems using more robust tools. However, this type of feedback can allow the designers to eliminate extremely inefficient design options very early on in the design process.

3.4.2 Interoperability

Although utilizing Building Information Models in energy analysis programs has been possible already for quite some time, we have still detected serious deficiencies in defining the needed information content important for energy analyses and particularly in the quality of the implementation of data interfaces by the BIM authoring programs.

The information content in a model in terms of energy analysis is not complicated, however, introducing all the necessary data in the model does not always guarantee the success of data transfer. Therefore, it is needed to define some detailed requirements for the utilization of BIM to support energy analysis.

By comparing gbXML schema with those derived of IFC schema, it should be noticed that gbXML is specifically targeted to exchanging information to engineering analysis, mainly thermal analysis, software. However, IFC has wider scope to support whole building and facility industry through the whole life cycle of a building and therefore, it does not work as well as gbXML to exchange information related to energy analysis. In order to allow interoperability through IFC it is advisable to follow rigorous rules of modeling which ensures a properly definition of the IFC schema.

The main limitations and issues detected during the proofs of concept using gbXML are as follows:

- Complex geometry (curved surfaced and so on) is difficult to export perfectly and does not always provide a reliable source of geometric data. Frequently, building elements may end up missing, misplaced, or deformed. When geometric errors occur, it is difficult to determine the source of error. As a general principle, the greater the complexity of a geometric model, the greater the risk for errors in translating that geometry from a BIM to an energy analysis tool.

- The usefulness and accuracy of the results depends on the quality of the inputs and if a BIM is correctly populated with the necessary information to successfully perform energy simulation. Otherwise, the majority of the time during energy analysis phase of a project can be spent on correctly modeling the building in a load-simulation program, such as Design Builder. Inaccurate or careless modeling of walls, partitions, floors, and ceilings can result in problems with space objects. The quality of the data transfer depends on four variables:
    - the quality of the building model (e.g. no missing elements or invalid wall connections)
    - the quality of the BIM-authoring tool writer/exporter
    - the ability of the data schema used to clearly organize the information
    - the building analysis tool translator/importer

- The ability to import construction thermal data into energy models directly from a BIM is limited. Actually, few BIM tools export this type of construction data in IFC or gbXML, and most building analysis tools do not import it. The data schemas do support this type of information, yet data structure protocols and organizational methodologies have yet be agreed upon and standardized across the industry.

In conclusion, it is recommended to minimize the number of unnecessary elements to be translated. In particular, it is not necessary to translate all the interior walls from a BIM into an energy simulation tool. This practice provides limited benefit in most energy simulations, since heat transfer between interior spaces with similar thermal conditions is generally negligible. Also, some energy simulation programs do not calculate heat transfer between interior surfaces. In these situations, the interior walls that do not separate thermal zones should be deleted, or at least modeled as separate elements such that export of the geometric model for analysis may be made without them.

3.4.3 Recommended BIM future developments

A future goal of BIM is to eliminate the need to make adjustments to the model, and enable the designer to seamlessly export the entire building information model to an energy analysis tool, independent of the level of complexity. Any modifications that need to be made would be automated in the export/import process by filtering out unnecessary elements.

The ability to import construction thermal data (material layer sets and material properties such as thermal conductivity, specific heat, emissivity, reflectivity) HVAC equipment data, and load data into energy models directly from a BIM would significantly reduce not only time in the energy modeling process, but also uncertainty. Automated association of construction type to thermal data, either within the BIM-authoring application or during import into an energy simulation, would be desirable.

Regarding HVAC equipment data and lighting load data, the ability to store operational data within a BIM object of the equipment would reduce the potential for incorrect assumptions and improve the process of information transfer.

Ideally, equipment manufactures could post BIM objects on their website for free download. This object would contain all the equipment properties, such as model, capacity, efficiency, performance curves, etc., in a format that is compatible with the most common BIM tools.

Another desirable option would be to have required mechanical/energy code assumptions based on industry standard sources of data (e.g. ASHRAE) automatically assigned to the space object based on space type selected.

4 BIM TOOLS PACKAGE

4.1 Tools selection

It is true that no one application will be ideal for all types of projects and the software application that best suits a project's goals will vary on a project-by-project basis. Besides, different combinations of tools may be used depending on the needs of the project.

Therefore, the choice of BIM tools involves making decisions based on convenience, functionality and the ability to store, refine and reuse data later in the life-cycle, taking into account the information exchange process.

Most of BIM applications are emerging tools which release new features in a year-to-year basis. For that reason, a specific tool cannot be selected only by its energy analysis functionalities. The election should take into account, at a minimum, next criteria:

- To be object oriented software applications which allow the creation of parametric and information rich-objects.
- To export gbXML or IFC (version 2x3 or newer[10]) file type standard. IFC including both coordination view and space boundary add-on view.
- To have some in-built energy analysis functionalities to support early design phases.
- To be capable of producing 2D drawings based on 3D models to fulfill the executive project and construction phases.

4.2 Tools to be used by each demo site

Next table shows the tools selected in each demo site to develop Building Information Models for NEED4B project. The election has been based on the criteria previously listed and the background of some of the partners.

DEMO SITE COUNTRY	MAIN BIM SOFTWARE used or to be used
Turkey	Autodesk Revit
Spain	Autodesk Revit
Italy	Autodesk Revit

[10] http://www.buildingsmart-tech.org/specifications/ifc-overview/ifc-overview-summary

Sweden	DDS-CAD
Belgium	Autodesk Revit

Table 8

5 GUIDELINES FOR BIM-BASED ENERGY ANALYSIS

5.1 BIM-based energy analysis uses

The potential utilization of Building Information models for energy analyses covers all stages of the project from conceptual design to operation and maintenance, including construction and commissioning. Next table shows potential utilization ways for BIM-based energy analyses throughout the project lifecycle and how detailed models should be.

PHASE	POTENTIAL USES	MODEL DETAIL*
Conceptual design	Early simulations supporting set up of energy targets (energy consumption and comfort). Comparison of alternatives (solar shading, facades, technical systems…)	Rough energy model with simplified building envelope, thermal zoning and data of window coverage (%). If structural types have not yet been defined in this phase, regulations can be used.
Design development	Further analysis of selected solutions during conceptual design. Simulations supporting set up of heating and AC requirements: air flows, cooling loads and heating losses.	Model with more detail data on structure, doors and windows types. Accurate thermal zoning with specific area and volume information.
Detailed design	Analysis of detailed design solutions' impact. Update of energy consumption estimate.	Mechanical, electrical and plumbing systems data included in the model.
Construction	Analysis of contractor's equipment selection impacts (if	Model with as-built conditions.

	changes had happened).	
Commissioning and warranty	Verification of resulted energy consumption and comfort to requirements.	Updated system operation data (usage profiles) included in the as-built model.
Operation and maintenance	Energy and comfort monitoring and verification to requirements. Update of energy consumption target.	As-built model linked to FM systems (measurements of comfort and energy performance).

* The level of detail is cumulative phase by phase

5.2 BIM-based energy modeling

5.2.1 Traditional energy modeling and BIM-based energy modeling

Traditional energy modeling refers to the process of independently constructing a model within an energy simulation program based on a proposed or existing building design. Usually, simplifications to the geometric design are required to make the input of the design into the simulation program manageable since these programs have some restrictions to model complex geometry. Such simplifications result in building models that serve as limited approximations of the building. In addition, if the building design changes, the energy model must be revised too, meaning a duplication of the modeling. All these factors result in a very time consuming process for designers.

BIM-based energy modeling has the potential to simplify the process described above by leveraging building information that exists in the building information models already created by the project design team. This information may include geometric data, construction types and the associated thermal properties, space loads, as well as other useful simulation parameters. Therefore, the geometry and other assumptions specified in the BIM are consistent across users and lifecycle. However, this process is not automatic and a methodology must be defined to create and transfer successfully a building information modeling to energy calculation software.

5.2.2 Recommendations for BIM-based energy modeling

As stated in section 3, the information content in a model in terms of energy analysis is not complicated, however, introducing all the necessary data in the model does not always guarantee the success of data transfer. Therefore, it is needed to define some detailed requirements for the utilization of BIM to support energy analysis uses described in the preceding section 3.1.

Appendix F describes specific guidelines to exchange BIM data from Revit to DesignBuilder based on the proof of concept carried out in task 2.3.

5.2.2.1 GEOMETRIC DEFINITION

To use appropriate tools: Building objects in a BIM are walls, doors, windows, floors, ceilings, roofs, beams, columns and other building components. In order for these objects to be included as the intended object types when exporting to IFC or gbXML, they must be created using the appropriate tool within BIM software. If these objects are created using the wrong toolset (for instance, inclined beam modeled as roof elements or columns modeled as very short walls), they will be an issue when exporting to IFC or gbXML and then imported in an energy analysis software. Therefore, whenever a tool is available in the BIM software to create the correct object type, it should be used.

Walls: They define vertical enclosure of spaces and are critical components in energy simulation. In order to be correctly exported to IFC or gbXML, walls must be connected to adjoining walls and the spaces they bound. Normally, these connections are automatic if the walls are properly modeled and the faces of the wall and the space are coplanar.

To model the minimum objects necessary based on the thermal zones. A useful methodology is to keep elements which separate different thermal zones, therefore needed for the energy simulation, on a separate layer or group from the elements that are not needed. Thus, it will be easier to export only the critical elements.

Not to create building objects that span several floors: This can cause problems when importing the BIM in an energy analysis tool. It is a good practice to model each object as only extending up one level, copy and paste that element on the level above it if needed.

Curtain walls: It is advisable to model curtain walls as 'contained' in a wall object to avoid problems with the exportation.

Windows and doors: Similar to curtain walls, they should always be inserted into a wall component and they must not extend outside the wall geometry.

Floors: It is essential that the floors are modeled as slab objects and that the joints between walls and slabs are modeled as accurately as possible for export of the BIM for accurate thermal analysis.

Shading devices: It could be better to model the shading devices directly inside the energy analysis tools instead of within the BIM tools, since IFC and gbXML could not correctly interpret these elements.

To maintain unique GUIDs to support data in workflows. Globally Unique Identifier is a unique code identifying each object of the BIM. The GUID assigned by the BIM authoring tool persists through name changes and various other modifications, allowing the object to be tracked throughout the project execution process

5.2.2.2 SPACE DEFINITION

Spaces are one of the most important object types in energy simulations. The space is usually created automatically with its geometry aligned with the inside faces of surrounding building elements (e.g. walls, floors, ceilings…). If the geometry of these building elements changes, the space object should also be updated to reflect the new geometry of the space.

Spaces should be modeled with finished floor to finished ceiling. When a space contains suspended ceilings and the resulting plenum area, spaces must be made for both the room space and the plenum space.

Ensuring that space heights are properly defined is a critical step in the process of exporting the model to an IFC or gbXML file. In addition, all the areas must be defined as spaces, regardless of how small they are. Otherwise, some walls could be erroneously considered as exterior.

Modeling practices for space differ lightly between software applications. Therefore, spaces should be checked visually in a 3D view before the exportation to ensure they are modeled with the correct height.

If two areas have different functional space classifications they shall be modeled as two separate spaces, even if they are within the same physical space.

5.2.2.3 LEVEL OF DETAIL REQUIRED

The models shall be created to a level of detail and quality enough to perform an energy analysis appropriate for the phase of the project. For example, to use BIM for thermal analysis, the walls must connect to each other at the corners, since a small gap can significantly interfere with the simulation.

During the modeling process, make sure not to be too detailed. Energy modeling for many of the BIM tools is best done at a very basic level. Adding lots of detail takes more time for testing options that may not be used. Energy analyses are processor-heavy operations that are often rough results of many variables. Simple and basic models work better.

5.3 BIM-based Conceptual Energy Analysis

As found in the early proof of concept, energy analysis, based on Building Information Models, carried out during conceptual design phase is one of the most profitable and helpful analysis supporting the energy efficient buildings design.

Next diagram summarizes the general workflow to follow in order to perform a BIM-based conceptual energy analysis on a general basis, regardless of the BIM tool used.

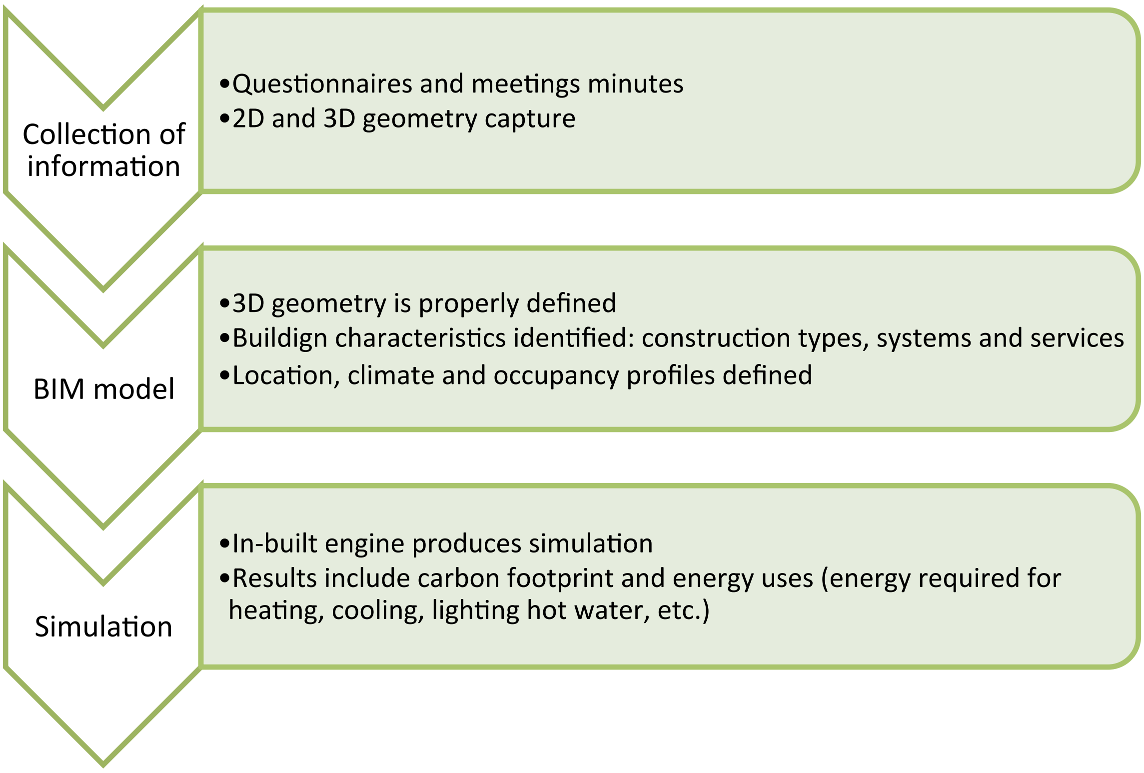

Figure 24: BIM-based conceptual energy analysis workflow

The first step is to gather the information about the building. A basic schema of the information required is listed as follows:

Geometry	Floor area, number of floors and form
Location and orientation	Right location since climate seriously affects energy simulation
Construction types	Materials and construction technologies of walls, slabs, roofs, windows and other building elements
Services and systems	Heating, Ventilation and Air Conditioning Lighting IT and control systems
Occupancy	Use of the building Number of people inside Schedule
Loads	Machinery Extra requirements

Table 9: Required information for energy modeling

The conceptual BIM can be based on sketches or 2D drawings with low level detail. It will be a mass model where different spaces or thermal zones are specified. With the geometry model finalized and energy parameters introduced, the model can be analyzed.

Finally, the conceptual energy analysis performing will provide an estimate of energy demand of a building's energy performance, based on high level data about its geometry, location and design, permitting quicker analysis based on broader parameters and a higher level of assumption, although with lower accuracy than the traditional energy analysis.

In Appendix G, it is described the workflow followed to perform a BIM-based energy analysis in Autodesk Revit and Vasari.

5.4 BIM modeling and analysis plan

In order to use effectively Building Information Models (modeling and analysis), collaboration between stakeholders is required along the project's lifecycle. That collaboration may cause confusion and difficulties during the project development if it is not properly planned. Therefore, it is recommended to create a document to establish organizational and project standards and responsibilities and ensure that all stakeholders get the information they need during every phase of the building project.

In addition, this document will clearly outline the scope of the BIM-based energy modeling activities to meet the energy goals as well as summarizes all the relevant energy modeling inputs, assumptions and results.

Once the plan is created, the team can follow and monitor their progress against it to gain the maximum benefits from BIM.

The BIM modeling and analysis Plan should contain:

- Project description
- BIM goals for the project and specific BIM uses
- BIM team description
- Planned models and analysis tools
- Modeling standards
- BIM-based project deliverables
- Project phases or milestones

Some of the items of the Plan may be challenging to complete, therefore as much as possible should be completed and the remaining should be completed when the information becomes available. Therefore, the BIM Plan should be a living document which should be reviewed and updated on a periodic basis.

In Appendix H, there is a template to support demo sites coordinators to develop the BIM modeling and analysis plan.

6 CONCLUSIONS: BIM INFORMATION EXCHANGE IN NEED4B PROJECT

6.1 NEED4B methodology

NEED4B project aims to develop an open and easily replicable methodology for designing, constructing and operating new low energy buildings, aiming to a large market uptake. It will integrate tools and procedures that already exist or are under development, like IPD, BIM, LCA, LCC and simulation software, providing recommendations and guidelines adapted to the different type of AEC stakeholders for the whole construction process.

IPD methodology introduces a collaborative approach to the AEC processes, bringing together stakeholders' point of view from the very beginning of the project. BIM is the best tool to achieve this integrated management of the building projects as it provides the technology to support the interdisciplinary collaboration of IPD.

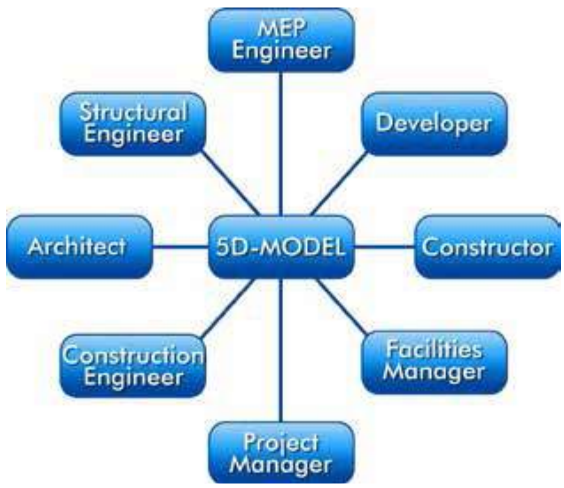

Figure 25: Integrated workflow (5D model = BIM model)

The diagram below depicts a typical Building Information Modeling process: different models are usually created by discipline (one from the Architect's side, one from the Structural Engineer's side and one from the MEP Engineer's side), then they are merging and collaboratively checking and finally they are simulated and analyzed to find out the optimum design. When the design is approved, the Construction Documentation is developed based on the BIM previously done and agreed.

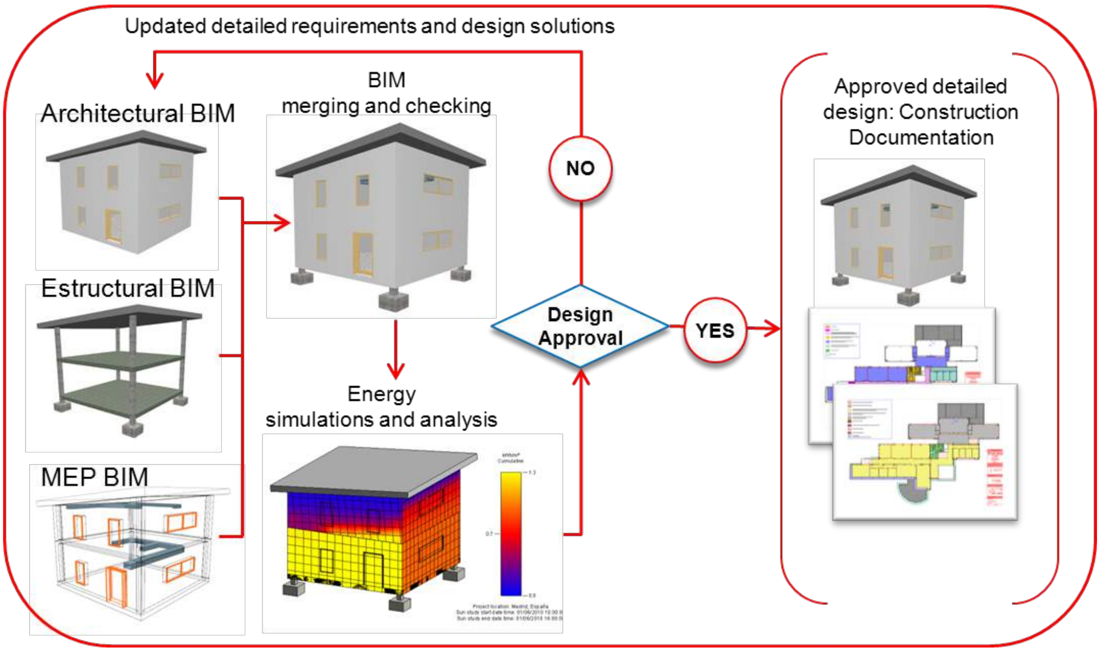

Figure 26: Typical BIM processes

The design process using BIM is iterative, that is, the analyses can be performed at several times within the Project lifecycle since making changes in the BIM model are less time-consuming than making them in the traditional approach. This supports decisions-making process and better designs and allows the design team to perform what-if scenarios to compare and balance cost, quality, and sustainability

In addition to energy analysis, BIM can expand its use to other analysis during the whole life cycle of the building and integrate its rich data with many other AEC technology tools like LCC/LCA or FM tools. The BIM model provides an effective platform to overcome the difficulties of acquiring the necessary building data in LCA/LCC and FM. And thus, it provides great potential for conducting whole building LCA in the design stage and using ‘as-built’ BIM models as basis for Facilities Management and Operation.

6.2 Integrated use of BIM in NEED4B demo sites

As a result of research and investigation conducted in Task 2.3 and outlined in the previous sections of this Deliverable report, next diagram shows the sequence of various processes to be performed by design and construction team of each demo site in order to achieve the design of energy efficient buildings through the use of the BIM methodology.

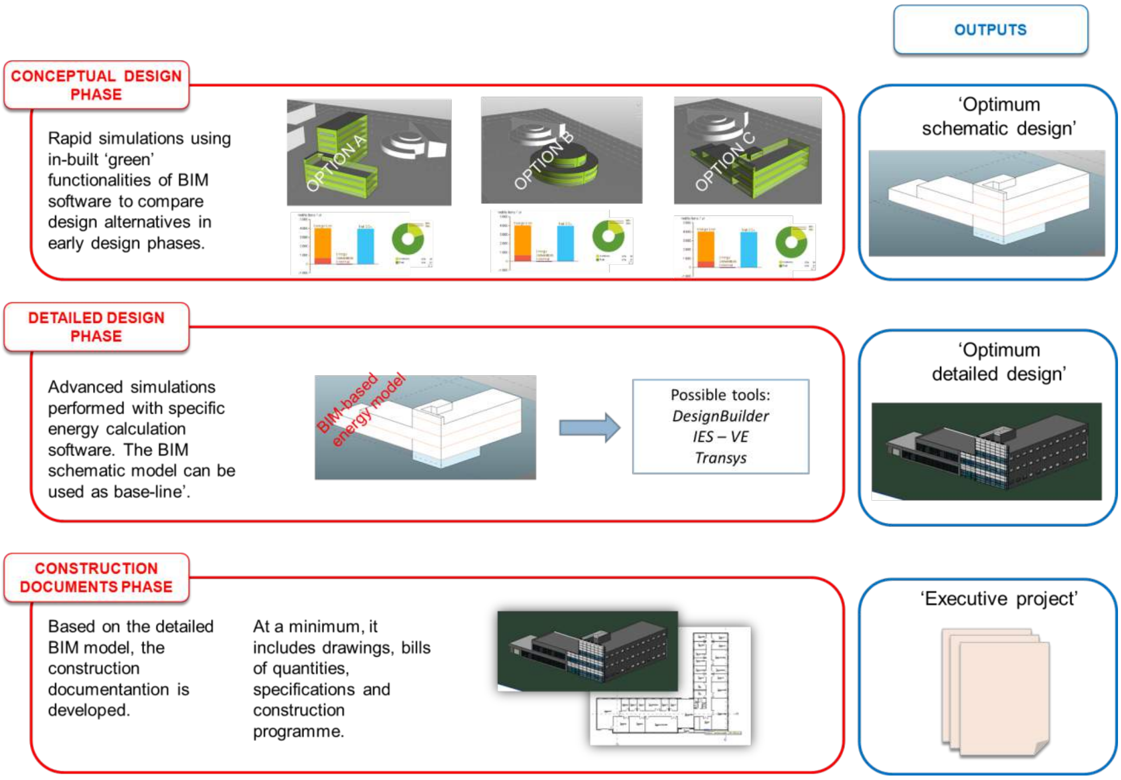

Figure 27: BIM-base design methodology for EEB design

During the very early design phase, rapid simulations using the functionalities included in the BIM tools will support the comparison of design alternatives based on their energy performance.

When the optimum schematic design is found, it will be used as baseline to perform more advanced simulations through specific software tools. From this analysis, interpreting its results, we will understand how suitable and feasible the construction technologies which shape the optimum detailed design are.

Once the optimum detailed design is defined, the construction documents phase starts and, based on the detailed BIM model, the construction documentation is developed.

The above diagram is flexible and could be customized depending on the project goals, which should be defined as explained in the BIM modeling and analysis Plan[11].

[11] See Appendix H: BIM modeling and analysis plan template

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8 Acronyms

AEC:	Architecture, Engineering and Construction
API:	Application Programming Interface
ASHRAE:	American Society of Heating, Refrigerating and Air Conditioning Engineers
BIM:	Building Information Modeling/Model
BREEAM:	Building Research Establishment Environmental Assessment Methodology
CEA:	Conceptual Energy Analysis
EEB:	Energy Efficient Buildings
FM:	Facility Management
GUID:	Global Unique Identified
HVAC:	Heating, Ventilation, and Air Conditioning
IFC:	Industry Foundation Classes (ISO 16739)
IPD:	Integrated Project Delivery
ISO:	International Organization for Standarization
LCA:	Life-Cycle Assessment
LCC:	Life-Cycle Cost
LEED:	Leadership in Energy and Environmental Design
MEP:	Mechanical, Electrical and Plumbing
XML:	eXtendable Mark-up Language

APPENDIX A: Software surveys of Task 1.3

Next tables show a summary of surveys about software answered by partners in Task 1.3.

PARTNER / DEMOSITE		FUNCTIONALITY		SOFTWARE	INPUT	OUTPUT
TURKEY	OZU	CAD software for drawing creation	ARCHITECTURAL, STATICS, MEP DRAWINGS, SCALING, MEASURING,ETC.	AUTOCAD LT CLASSIC 2011 REVIT	Scale and measures (dimensions) (via 'Autocad Standard rules')	3D drawings (from Revit)
		BIM software		ARCHICAD (if needed)		
		Structural design/ analysis software	STATIC CALCULATIONS	SAP 2000 ETABS		
		MEP software / analysis software	HEAT GAIN AND HEAT LOSS CALCULATIONS. HOURLY RADIATION ANALYSES.	CARRIER E20 COOLING LOAD CALCULATIONS SOFTWARE	Standard: ASHRAE, TS 825,	
		FM software	DAY AND NIGHT MODES, ENERGY SAVING, MAINTENANCE PERIODS,	KMC – BUILDING MANAGEMENT SYSTEMS		
		Energy Modeling Software	ENERGY PERFORMANCE CERTIFICATE	INTERNET-BASED EPC MODELLING SOFTWARE	Standard: ALL TECHNICAL REGULATIONS	
		LCC/LCA Software		Sima Pro Gabi		

PARTNER / DEMOSITE		FUNCTIONALITY		SOFTWARE	INPUT	OUTPUT
BELGIUM	UMONS	CAD software for drawing creation	Creation of fast prototypes and models	Sketch Up 8	Coordinates in x and y axes. It has a simple and friendly user interface. It can handle labels and dimensioning tools	3D model (.dae)
		Energy Modeling Software	Energy modeling of buildings and their energy systems. Parameter analysis. Control and decision making.	TRNSYS16	Dimensions of building envelope, number of windows and types, type of lighting, type of heating systems… (ALPHANUMERIC)	Energy consumption (.txt) Temperature profiles (.txt)

PARTNER / DEMOSITE		FUNCTIONALITY		SOFTWARE	INPUT	OUTPUT
SPAIN	CIRCE	CAD software for drawing creation	Technical Drawing	AutoCAD CypeCAD		
		Structural design/ analysis software	building and construction design and calculations according to Spanish standards and regulations	CYPE		
		MEP software / analysis software	Design plumbing, electric layouts and anything concerning HVAC in buildings	AUTOCAD MEP CYPE		
		FM software	Building online monitoring and control	SCADA		

		Energy Modeling Software	Simulations of CO2 emissions in the usage phase of the building, therefore, to obtain an Energy Efficiency category depending on the structure, envelope, heating and cooling systems, hot water,…	CALENER VYP CALENER GT DESIGN BUILDER		
		LCC/LCA Software	To simulate and calculate LCA impact according to different methodologies.	Sima Pro		
				Gabi		

PARTNER / DEMOSITE		FUNCTIONALITY		SOFTWARE	INPUT	OUTPUT
ITALY	DAPPO	CAD software for drawing creation	Conceptual and detailed designing and virtual prototyping to perform 2D technical drawings	AUTOCAD 2013	Project sketches	2D drawings (dwg exported to FEM tools)
		Structural design/ analysis software	Conceptual and detailed designing and virtual prototyping to perform 3D technical drawings	Solidworks 2010	Project sketches	3D drawings (exported to FEM tools)
			Designing, virtual prototyping, structural, thermal, magnetic, seismic analysis to perform and verify design	Ansys 14, ANSYS inc	3D model in .x_t or .igs or .step file Material and loads and constrains (alphanumeric)	Analysis results (alphanumeric)

			Designing, virtual prototyping, dynamic and impact analysis to perform and verify design	Ls-Dyna, ANSYS inc	3D model in .x_t or .igs or .step file Material and loads and constrains in .k file format	Analysis results (alphanumeric) The file can be saved as .d3plot
			Structural Buildings Design, Bridges Design	SAP2000, v 15	CAD drawings CAD models, IGES files .s2k files Microsoft Access database, Microsoft Excel spreadsheets	Dxf files Dxf models .s2k files (to be exported to STAAD, GT Strudl) Microsoft Access database, Microsoft Excel Spreadsheets
			Structural Detailing Buildings Design	MODEST, v 7.27, Tecnisoft s.a.s.	Dxf files Dxf models	Dxf files Dxf models, VRML files Microsoft Access database, Microsoft Excel Spreadsheets
		LCC/LCA Softwar e	It is typically used for carrying out life cycle assessment analyses in order to provide, for instance, environmental impact of novel product/ process generation	GaBi,5	Material and energy flows info (alphanumerical) Standard import files are supported (.txt or .csv), or -specific import interfaces can be customized upon demand	Tables: Xls. Gbx (internal exchange format) Pictures: Possibility to copy charts and pictures to clipboard as .jpg
		OTHER	To carry out material analysis. The supported functionalities are different; for example it can be used to explore material database and to compare a huge amount of	Granta CES Selector, 2010	Material constraint (alphanumeric)	Pictures, report, chart Producer reference link on the product family: .jpg, picture (enhanced metafile)

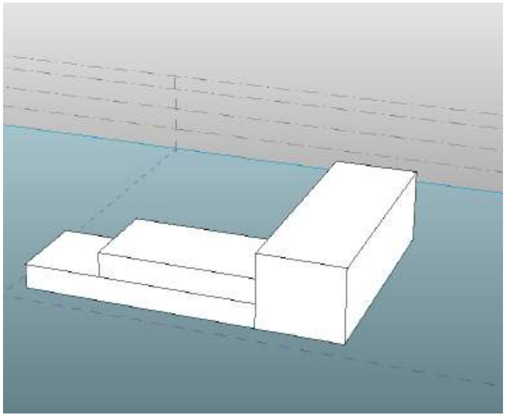
			materials according to different parameters (e.g. cost, Young Module, density, etc.)			

PARTNER / DEMOSITE		FUNCTIONALITY		SOFTWARE	INPUT	OUTPUT
ITALY	ANDREA MAFFEI ARCHITECTS	CAD software for drawing creation	All phases of project design	Autocad LT 2013	Distance, shortcuts, editing commands etc	Drawings with layers

APPENDIX B Data of the Vasari/Revit model

FORM

Geometry + Mass floors



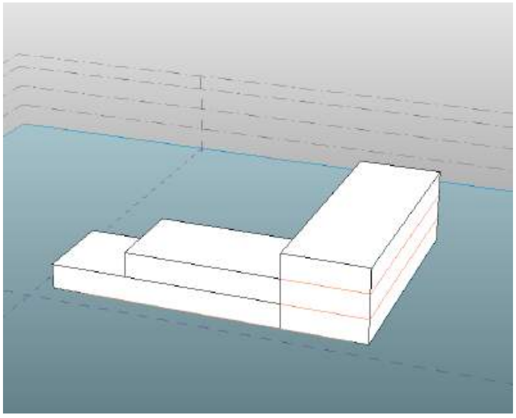


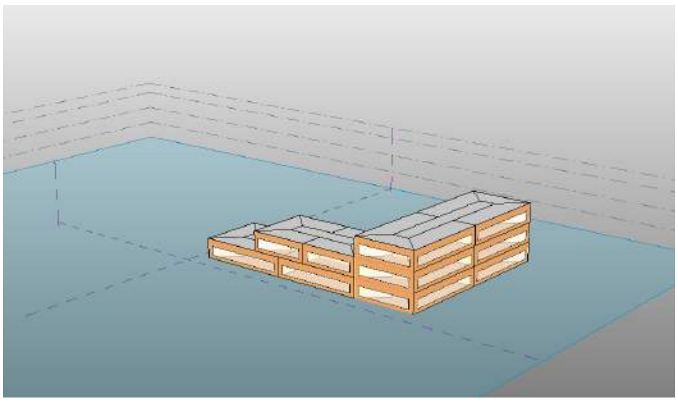
Figure 28: Geometric and mass floors models

Geometry: modeling the global conceptual form of the building

Mass floors: automatically created through the levels defined in Revit/Vasari as reference planes

DATA INCLUDED IN THE SURFACES

Conceptual construction systems + glazing + shading



Conceptual construction systems: construction materials and assemblies used for the different types of mass surfaces:

- Mass exterior wall
- Mass interior wall
- Mass exterior wall – underground

- Mass roof
- Mass floor
- Mass slab
- Mass glazing
- Mass skylight
- Mass shade (is assumed to be opaque)
- Mass opening (void in a surface that is exposed to climatic conditions)

Glazing: Several indicators are included.

- Target percentage glazing: the percentage of exterior walls to be glazed openings (windows). It is also known as the window-to-wall ratio (WWR).

- Target Sill Height: the distance from the floor to the bottom of the window.

These two indicators work together and are balanced automatically.

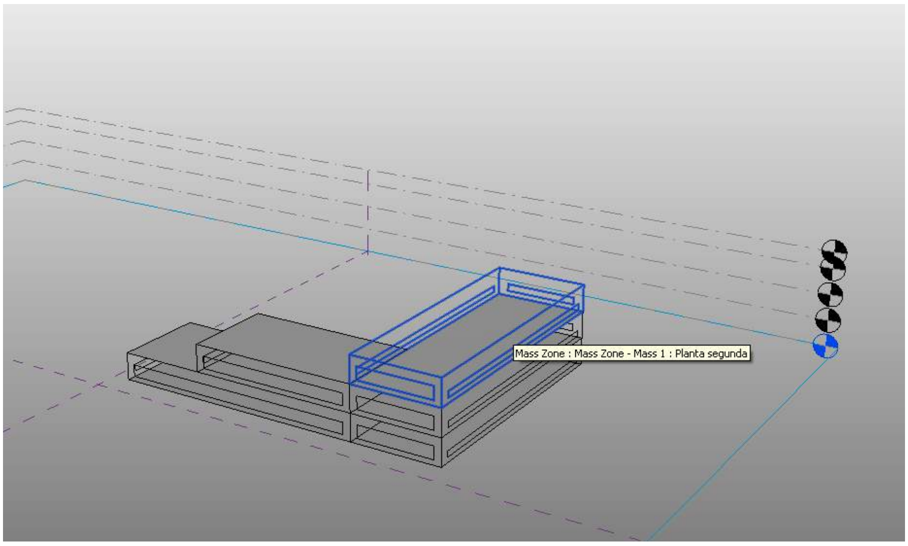
Shading: Several indicators are included.

- Glazing is shaded: Light shelves to shade windows and other glazing are added to the model

- Shade depth: The depth of the shades

DATA INCLUDED IN THE ZONES

Space type + Condition type



Space type: There are some predefined types. Data included in each type corresponds to:

- Occupancy schedule
- Power schedule
- Power Schedule Warehouse 7 am - 4 pm

- People/100 sq. M.
- People Sensible Heat Gain (Btu/hr)
- People Latent Heat Gain (Btu/hr)
- Lighting Load Density (W/sq. ft.)
- Power Load Density (W/sq. ft.)
- Electrical Equipment Radiant Percentage
- Infiltration Flow (CFM/sq. ft.)
- Carpet (Y/N)

Condition type: The space can be:

- Heated
- Cooled
- Heated and cooled
- Uncondionated
- Vented
- Natural vented only

COMMON DATA OF THE ENTIRE BUILDING MODEL

Building type: There are some predefined types. Data included in each type corresponds to:

- Occupancy Schedule
- People/100 sq. M.
- People Sensible Heat Gain (W/person)
- People Latent Heat Gain (W/person)
- Lighting Load Density (W/sq. M.)
- Equipment Load Density (W/sq. M.)
- Infiltration Flow (ACH)
- Outside Air (ventilation air) Flow Per Person (liters per second)
- Outside Air (ventilation air) Flow Per Area (cubic meters per hour per square meter)
- Unoccupied Cooling Set Point (C)

Some of this data can be individually modified by zone (see the section above).

Location: The climatic data to be used can be chosen through an Internet Mapping Service which shows some weather stations close to the project location.

Ground plane: Level to use as the ground plane reference for the building. Spaces below this level are considered to be underground.

Building Operating Schedule: It overrides the default schedule for the specified building type. It provides information about occupancy assumptions based on ASHRAE standards.

HVAC system: There are some predefined types.

Outdoor air information: It can be defined as:

- Outdoor air per person >> The rate of outdoor air exchange measured in terms of CFM (cubic feet per minute) per person

- Outdoor air per area >> The rate of outdoor air exchange measured in terms of CFM per square foot of occupied floor area

- Air changes per hour >> The number of times in one hour that the total volume of air in the building is replaced with outdoor air

APPENDIX C: Conceptual energy analysis results

Next images show the results obtained of an energy analysis of Spain demosite's building early design performed with Vasari.

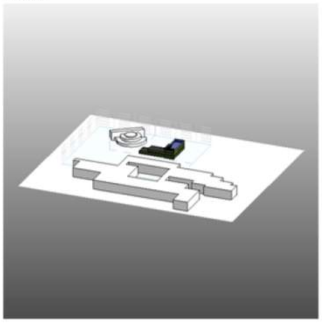
Autodesk Revit Conceptual Energy Analysis Report

Project2_30_10_12_deliverable1

Spanish demosite_early energy analysis

Analyzed at 12/13/2012 10:25:12 AM

Mass



Building Performance Factors

Location:	41,6844520568848,-0,883809328079224
Weather Station:	138733
Outdoor Temperature:	Max: 39°C/Min: -5°C
Floor Area:	2,718 m²
Exterior Wall Area:	1,892 m²
Average Lighting Power:	15.07 W / m²
People:	151 people
Exterior Window Ratio:	0.20
Electrical Cost:	$0.13 / kWh
Fuel Cost:	$1.23 / Therm

Energy Use Intensity

Electricity EUI:	1,719 kWh / sm / yr
Fuel EUI:	24,236 MJ / sm / yr
Total EUI:	30,426 MJ / sm / yr

Life Cycle Energy Use/Cost

Life Cycle Electricity Use:	140,200,590 kWh
Life Cycle Fuel Use:	1,976,339,475 MJ
Life Cycle Energy Cost:	$18,384,574

*30-year life and 6.1% discount rate for costs

Renewable Energy Potential

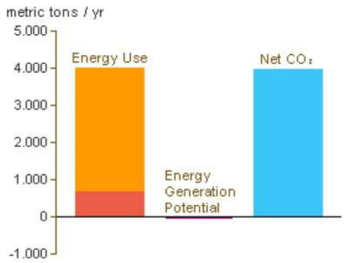
Roof Mounted PV System (Low efficiency):	96,639 kWh / yr
Roof Mounted PV System (Medium efficiency):	193,278 kWh / yr
Roof Mounted PV System (High efficiency):	289,917 kWh / yr
Single 15' Wind Turbine Potential:	2,139 kWh / yr

*PV efficiencies are assumed to be 5%, 10% and 15% for low, medium and high efficiency systems

Annual Carbon Emissions

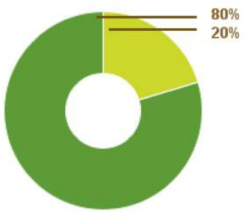
1

Autodesk Revit Conceptual Energy Analysis Report



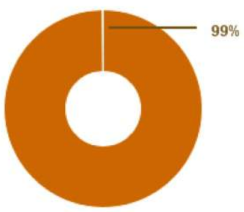
	(metric tons / yr)
Electricity Consumption	712
Fuel Consumption	3,285
Roof PV Potential (High Efficiency)	-44
Single 15' Wind Turbine Potential	0
Net CO_2	3,953

Annual Energy Use/Cost



Electricity	20%	$584,169	4,673,353	kWh
Fuel	80%	$765,653	7E+007	MJ
		$1,349,822		

Energy Use: Fuel

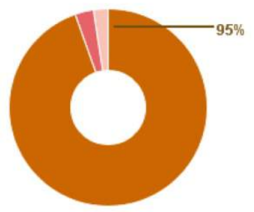


			(MJ)
HVAC	99%	$764,540	7E+007
Domestic Hot Water	1%	$1,112	95,731
		$765,652	7E+007

Energy Use: Electricity

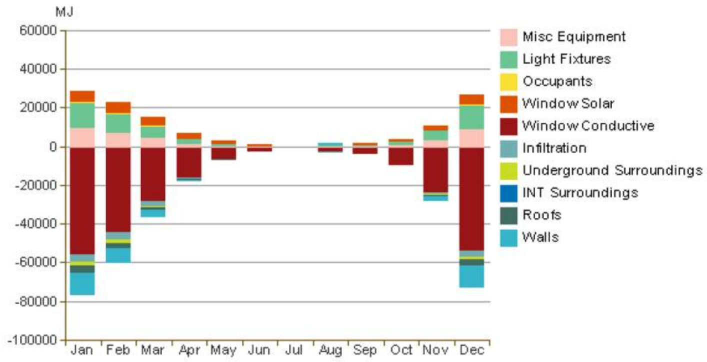
2

Autodesk Revit Conceptual Energy Analysis Report

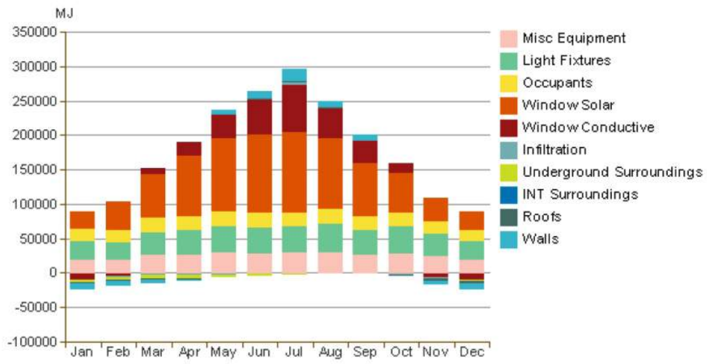


			(kWh)
HVAC	95%	$551,780	4,414,245
Lighting	3%	$17,568	140,548
Misc Equipment	2%	$13,977	111,818
		$583,325	4,666,611

Monthly Heating Load



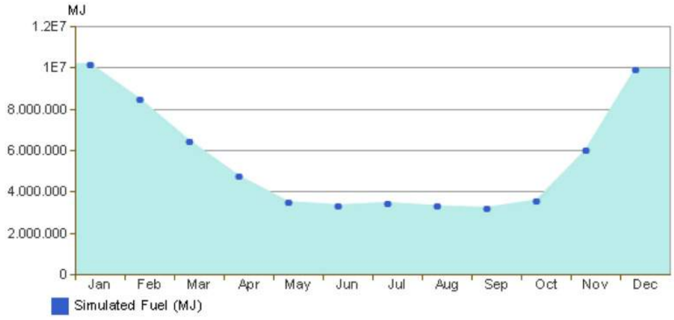
Monthly Cooling Load



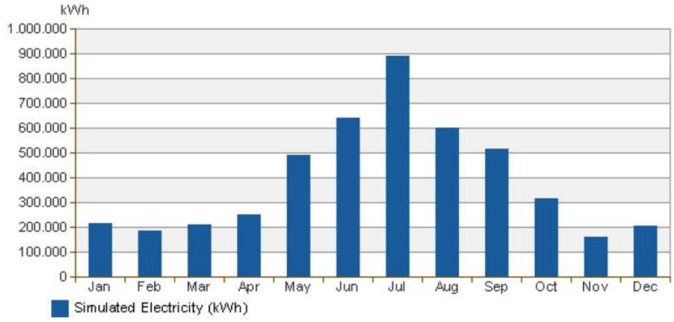
Monthly Fuel Consumption

3

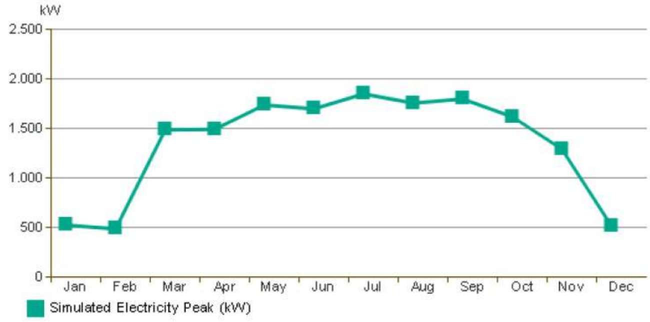
Autodesk Revit Conceptual Energy Analysis Report



Monthly Electricity Consumption

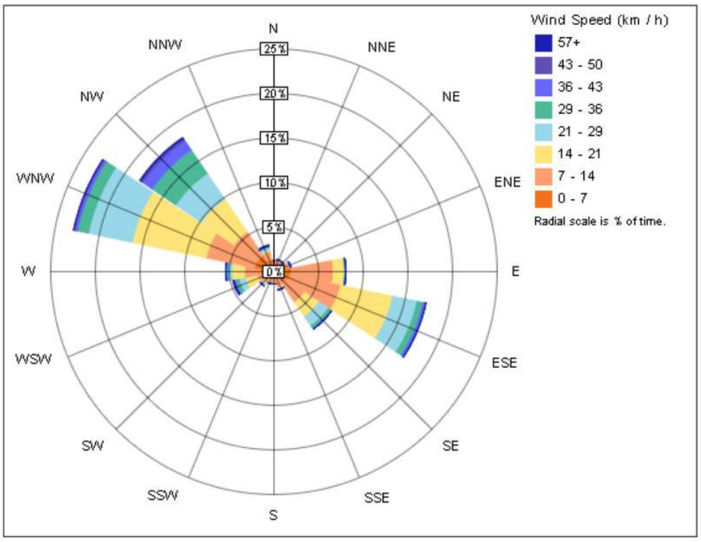


Monthly Peak Demand

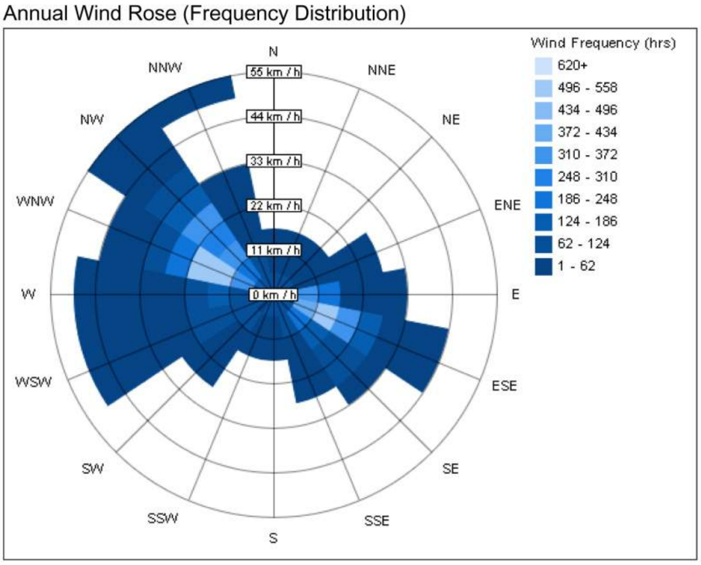


Annual Wind Rose (Speed Distribution)

Autodesk Revit Conceptual Energy Analysis Report



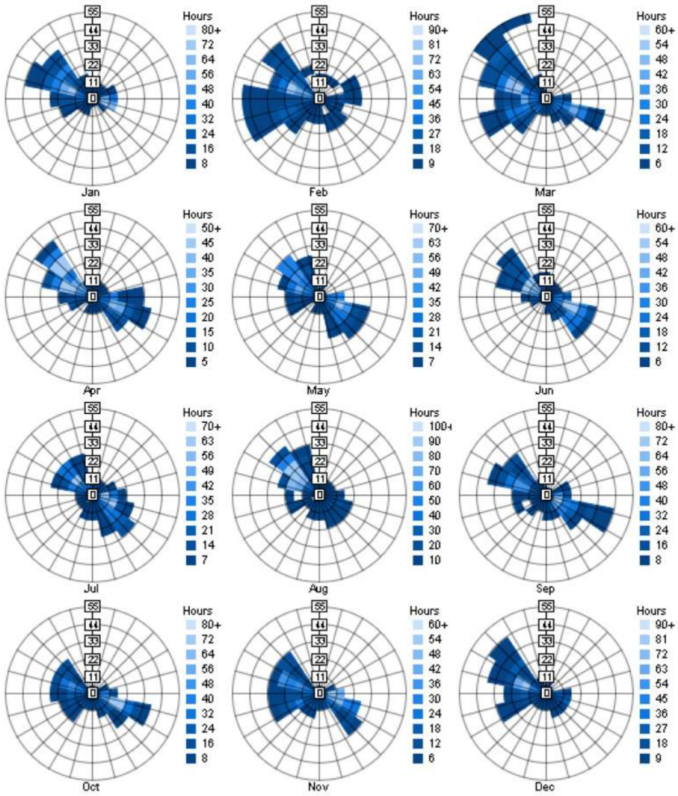
Annual Wind Rose (Frequency Distribution)



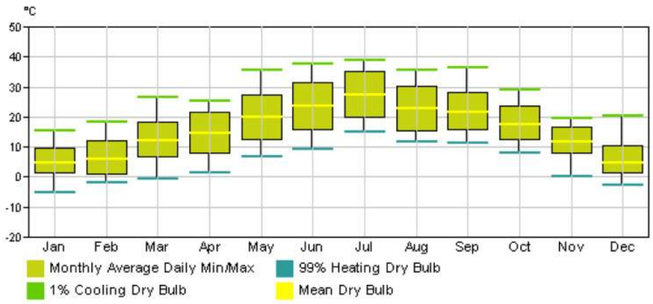
Monthly Wind Roses

5

Autodesk Revit Conceptual Energy Analysis Report



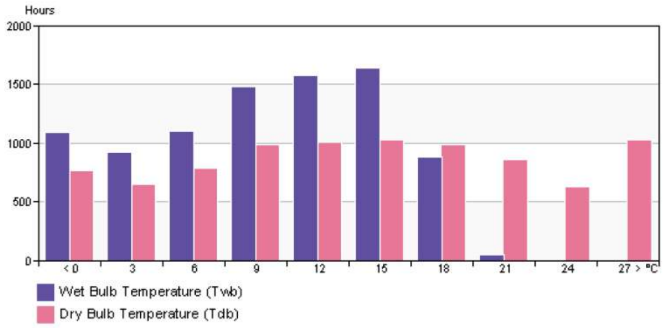
Monthly Design Data



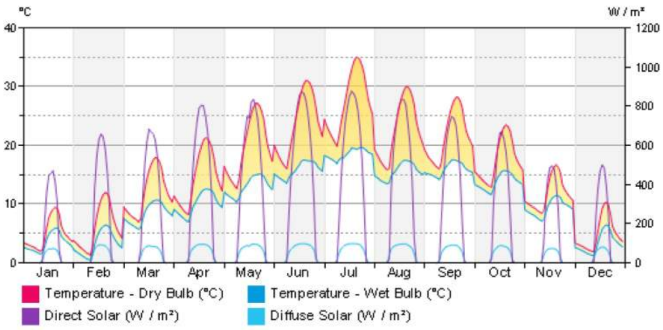
Annual Temperature Bins

6

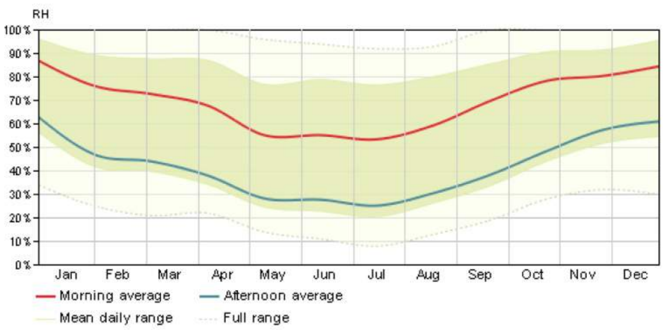
Autodesk Revit Conceptual Energy Analysis Report



Diurnal Weather Averages



Humidity



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APPENDIX D: Checklist exported properties table

Next images depict a checklist used during the proof of concept in order to find out which properties are well exported from Vasari to Design Builder through the gbXML exchange schema.

Building CIRCE II
Proof of concept

Exportation test to DB from Vasari through gbXML

Test #01

FILE NAME:	EXPORTATION SETTINGS	
Project1.xml	Category	Rooms
	Complexity	Simple with Shading Surfaces

DATA TYPE		Data inserted in Vasari	Data well exported (Y/N - details-)
Geometry		Basic geometry with levels defined and rectangular forms	YES
	Zones	Entire building divided in zones	YES
	Surfaces	Envelope, roof and slabs as individual surfaces	YES
Conceptual construction systems		Basic construction assemblies and systems defined	NO DATA IS EXPORTED
	Mass exterior wall	High Mass Construction – Typical Cold Climate Insulation	NO
	R- value - W/(m2*K)	2.58	
	Unit density (kg/m2)	477.14	
	Heat capacity - J/(m2*K)	1.081	
	Mass interior wall	Lightweight Construction – No Insulation	NO
	R- value - W/(m2*K)	0.49	
	Unit density (kg/m2)	455.55	
	Heat capacity - J/(m2*K)	0.193	
	Mass exterior wall – underground	High Mass Construction – Typical Mild Climate Insulation	NO
	R- value - W/(m2*K)	1.91	
	Unit density (kg/m2)	512.67	
	Heat capacity - J/(m2*K)	1.080	
	Mass roof	Typical Insulation - Cool Roof	NO
	R- value - W/(m2*K)	22	
	Unit density (kg/m2)	10	
	Heat capacity - J/(m2*K)	3	
	Mass floor	Lightweight Construction – Low Insulation	NO
	R- value - W/(m2*K)	2.48	
	Unit density (kg/m2)	48.57	
	Heat capacity - J/(m2*K)	0.066	
	Mass slab	High Mass Construction – No Insulation	NO
	R- value - W/(m2*K)	1.08	
	Unit density (kg/m2)	602.93	
	Heat capacity - J/(m2*K)	1.203	
	Mass glazing	Double Pane Clear – LowE Cold Climate, High SHGC	NO
	R- value - W/(m2*K)	1.96	
	Unit density (kg/m2)	0.67	
	Heat capacity - J/(m2*K)	0.72	
	Mass skylight	Not applied	NO
	R- value - W/(m2*K)		
	Unit density (kg/m2)		
	Heat capacity - J/(m2*K)		
	Mass shade	Not applied	NO
	R- value - W/(m2*K)		
	Unit density (kg/m2)		
	Heat capacity - J/(m2*K)		
	Mass opening	Not applied	NO
	R- value - W/(m2*K)		
	Unit density (kg/m2)		
	Heat capacity - J/(m2*K)		
Glazing			NO DATA IS EXPORTED

Building CIRCE II
Proof of concept

Exportation test to DB from Vasari through gbXML

Test #01

DATA TYPE	Data inserted in Vasari	Data well exported (Y/N - details-)
Target percentage glazing		NO
North façade	20%	
South façade	40%	
West façade	20%	
East façade	20%	
Target sill height	0.75meters	NO
Building Type	Workshop	NO DATA IS EXPORTED
Occupancy Schedule	see building operation schedule'	NO
People/100m2	5	NO
People Sensible Heat Gain (W/person)	73.3	NO
People Latent Heat Gain (W/person)	58.6	NO
Lighting Load Density (W/m2)	10.9	NO
Equipment Load Density (W/m2)	10.8	NO
Infiltration Flow (ACH)	0.1	NO
Outside Air (ventilation air) Flow Per Person (l/s)	3.1	NO
Outside Air (ventilation air) Flow Per Area (m3*h/m2)	3.7	NO
Unoccupied Cooling Set Point (C)	29.4	NO
Location	Climatic data from green building studio	NO
Ground plane	Planta baja	YES, WELL EXPORTED
Building operating schedule	12/5 facility (L-V 8-20h)	NO
HVAC system	Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff	NO
Outdoor Air information	0.73 LPS/m²	NO
Space type	All spaces with global definitions based on 'building type'	NO
Condition type	All spaces are 'Heated and cooled'	NO

APPENDIX E: Connection and information exchange between DDS-CAD and TEK

Data information from BIM model developed in DDS-CAD can be imported to the Norwegian Energy calculation program TEK[12]. It is an EPBD calculation tool that can be used for checking compliance to the Norwegian building regulations. Next images show some screenshots of that tool, with data imported from a BIM model (white tabs).

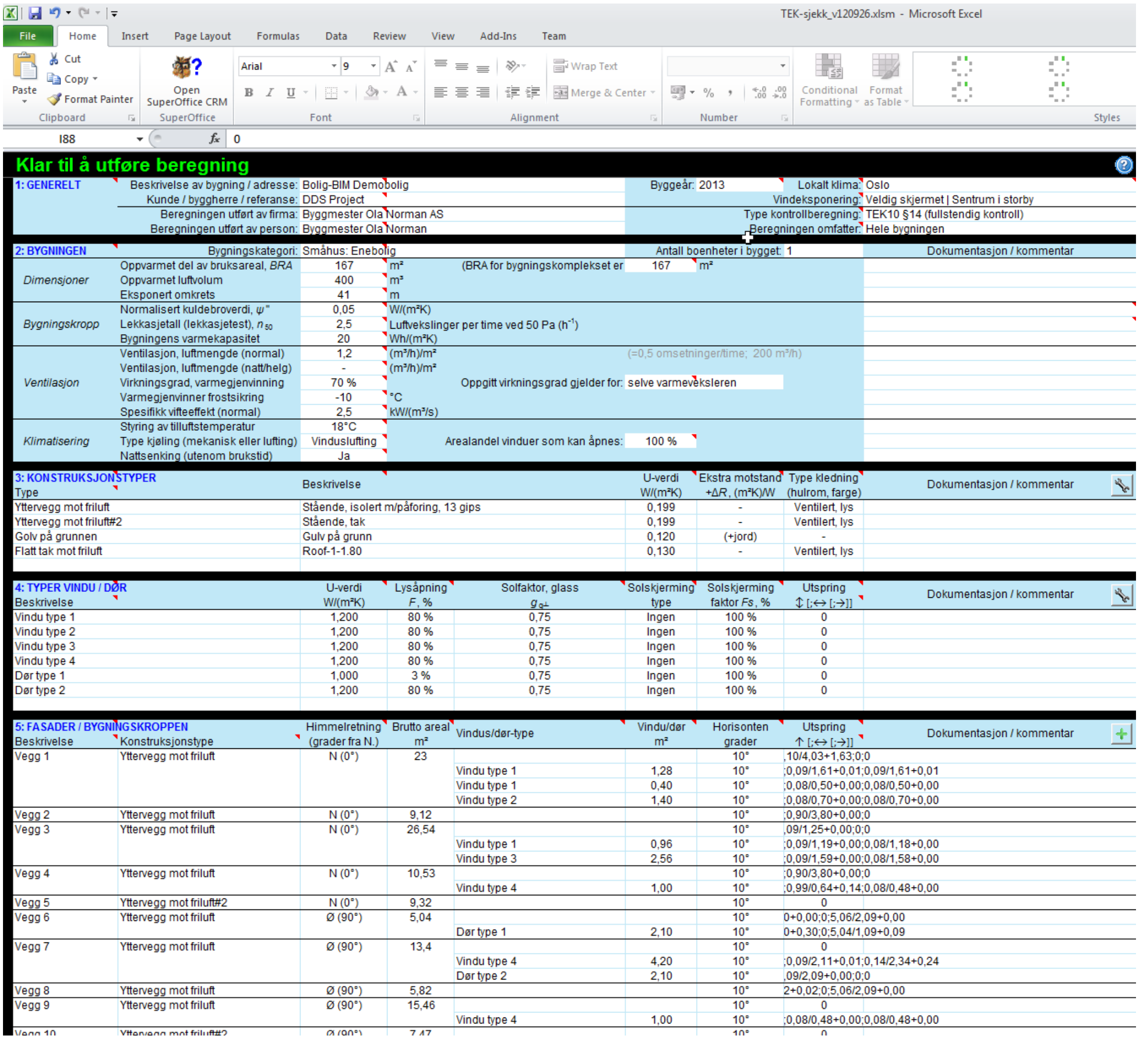


Figure 29

[12] http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=612/pagename=alpha_list_sub

Klar til å utføre beregning				
1: GENERELT	Beskrivelse av bygning / adresse:	Bolig-BIM Demobolig		
	Kunde / byggherre / referanse:	DDS Project		
	Beregningen utført av firma:	Byggmester Ola Norman AS		
	Beregningen utført av person:	Byggmester Ola Norman		
2: BYGNINGEN	Bygningskategori:	Småhus: Enebolig		
Dimensjoner	Oppvarmet del av bruksareal, *BRA*	167	m²	(BRA for b
	Oppvarmet luftvolum	400	m³	
	Eksponert omkrets	41	m	
Bygningskropp	Normalisert kuldebroverdi, *ψ''*	0,05	W/(m²K)	
	Lekkasjetall (lekkasjetest), n_{50}	2,5	Luftvekslinger per time v	
	Bygningens varmekapasitet	20	Wh/(m²K)	
Ventilasjon	Ventilasjon, luftmengde (normal)	1,2	(m³/h)/m²	
	Ventilasjon, luftmengde (natt/helg)	-	(m³/h)/m²	
	Virkningsgrad, varmegjenvinning	70 %		Oppgitt vi
	Varmegjenvinner frostsikring	-10	°C	
	Spesifikk vifteeffekt (normal)	2,5	kW/(m³/s)	
Klimatisering	Styring av tilluftstemperatur	18°C		
	Type kjøling (mekanisk eller lufting)	Vinduslufting		Arealandel vi
	Nattsenking (utenom brukstid)	Ja		

Figure 30

Point 1 describes general information as address, customer and building company. In point 2, building and systems are described:

- Usable floor area
- Heated air-volume
- Building circumference
- Thermal bridges
- Air change rate
- Thermal capacity
- Thermal efficiency
- Type of ventilation (mechanical or natural draught)
- Walls
- Floors
- Roof

Point 4 describes includes components in climate shield as windows and doors with theirs U-value and how many percent of the component are glazed, and also solar heat gains.

3: KONSTRUKSJONSTYPER Type	Beskrivelse	U-verdi W/(m²K)
Yttervegg mot friluft	Stående, isolert m/påforing, 13 gips	0,199
Yttervegg mot friluft#2	Stående, tak	0,199
Golv på grunnen	Gulv på grunn	0,120
Flatt tak mot friluft	Roof-1-1.80	0,130

4: TYPER VINDU / DØR Beskrivelse	U-verdi W/(m²K)	Lysåpning F, %	Solfaktor, glass $g_{g\perp}$	Solskjerming type
Vindu type 1	1,200	80 %	0,75	Ingen
Vindu type 2	1,200	80 %	0,75	Ingen
Vindu type 3	1,200	80 %	0,75	Ingen
Vindu type 4	1,200	80 %	0,75	Ingen
Dør type 1	1,000	3 %	0,75	Ingen
Dør type 2	1,200	80 %	0,75	Ingen

Figure 31

Point 5 describes the different walls and their geographical orientation; it also describes each wall area, types of window and sun shading.

5: FASADER / BYGNINGSKROPPEN Beskrivelse	Konstruksjonstype	Himmelretning (grader fra N.)	Brutto areal m²	Vindus/dør-type	Vindu/dør m²	Horisonten grader	Utspring ↑ [;↔ [;→]]	Doku
Vegg 1	Yttervegg mot friluft	N (0°)	23			10°	,10/4,03+1,63;0;0	
				Vindu type 1	1,28	10°	;0,09/1,61+0,01;0,09/1,61+0,01	
				Vindu type 1	0,40	10°	;0,08/0,50+0,00;0,08/0,50+0,00	
				Vindu type 2	1,40	10°	;0,08/0,70+0,00;0,08/0,70+0,00	
Vegg 2	Yttervegg mot friluft	N (0°)	9,12			10°	;0,90/3,80+0,00;0	
Vegg 3	Yttervegg mot friluft	N (0°)	26,54			10°	,09/1,25+0,00;0;0	
				Vindu type 1	0,96	10°	;0,09/1,19+0,00;0,08/1,18+0,00	
				Vindu type 3	2,56	10°	;0,09/1,59+0,00;0,08/1,58+0,00	
Vegg 4	Yttervegg mot friluft	N (0°)	10,53			10°	;0,90/3,80+0,00;0	
				Vindu type 4	1,00	10°	;0,99/0,64+0,14;0,08/0,48+0,00	
Vegg 5	Yttervegg mot friluft#2	N (0°)	9,32			10°	0	
Vegg 6	Yttervegg mot friluft	Ø (90°)	5,04			10°	0+0,00;0;5,06/2,09+0,00	
				Dør type 1	2,10	10°	0+0,30;0;5,04/1,09+0,09	
Vegg 7	Yttervegg mot friluft	Ø (90°)	13,4			10°	0	
				Vindu type 4	4,20	10°	;0,09/2,11+0,01;0,14/2,34+0,24	
				Dør type 2	2,10	10°	,09/2,09+0,00;0;0	
Vegg 8	Yttervegg mot friluft	Ø (90°)	5,82			10°	2+0,02;0;5,06/2,09+0,00	

Figure 32

The result page shows the result of the energy demand for:

- Heating
- Ventilation
- Circulation pump
- Lightning
- Household electricity

The total energy demand is calculated and divided by heated floor area, green digits display the sum and below the limit value according to the national regulatory requirements is displayed. This page also shows U-values and compares them with different levels in the national regulation requirement.

NETTO ENERGIBEHOV (normalklima)

Energipost	Energibehov kWh/år	Spesifikt behov kWh/(m²år)
Romoppvarming	9089	54,4
Ventilasjonsvarme	986	5,9
Varmtvann	4974	29,8
Vifter	1219	7,3
Pumper	128	0,8
Belysning	1902	11,4
Teknisk utstyr	2926	17,5
Romkjøling	-	-
Ventilasjonskjøling	-	-
Sum denne bygning:	21224	127
Krav i TEK10 §14-4 ≤	-	130
	-	-

VARMETAPSBUDSJETT

Varmetapspost	Netto areal m²	U-verdi [W/m²K] Denne bygning	TEK10 §14-3(1) energitiltak	TEK10 §14-5 minstekrav	Varmetap [(W/K)/m²] Denne bygning	TEK10 §14-3(3) ramme
Vegger	222,2	0,199	0,18	0,22	0,265	0,239
Tak	83,3	0,130	0,13	0,18	0,065	0,065
Gulv	79,8	0,106	0,15	0,18	0,051	0,072
Vinduer & dører	33,0	1,187	1,20	1,60	0,235	0,240
Kuldebro	167,0	ψ"=0,05	ψ"=0,03	-	0,050	0,030
Infiltrasjon	-	n_{50}=2,5	n_{50}=2,5	n_{50}=3	0,138	0,138
Ventilasjon	-	$\eta_{år}$≈70%	$\eta_{år}$=70%	-	0,119	0,119
Bygningens varmetapstall, *H"* [(W/K)/m²]:					0,922	0,903

ENERGIFORSYNING (normalklima)

Energivare	Levert energi kWh/år	Spesifikk levert kWh/(m²år)	Dekningsgrad varmebehov
Direktevirkende el.	11487	69,0	34,6 %
El. til VP & solenergi	4797	29,0	65,4 %
Olje	-	-	-
Gas	-	-	-
Fjernvarme	-	-	-
Biobrensel	-	-	-
Annen fornybar	-	-	-
Sum denne bygning:	16284	98	100,0 %
Varme fra fossilt/dir.el:	5205	-	34,6 %
Krav i TEK10 §14-7 ≤	-	-	60,0 %

Tilleggsinfo, dekningsgrad pr energisystem (normalklima)

Energisystem	Dekning av netto energibehov, kWh/år Romoppv.	Vent.varme	Varmtvann	Romkjøling	Vent.kjøl,	El.spesifikt	Dekningsgrad av total behov	System-virkningsgrad
El.varmepumpe	6362	-	3482	-	-	-	70 %	2,05
Elektrisitet	2727	986	1492	-	-	6175	54 %	0,99
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
Total behov:	9089	986	4974	-	-	6175		

(CO_2 utslipp cirka 38 kg/m² pr år ved normalklima)

SAMMENDRAG

Energi: ► Boligen tilfredsstiller kriteriene i TEK10 §14 (fullstendig kontroll)

Innemiljø: Boligen får stort solvarmetilskudd på fasader mot øst/sør/vest. Dette kan løses med god solskjerming.
Estimert gjennomsnittlig dagslysfaktor i boligen er 3,8%. Anbefalt grenseverdi er >2,5%. For god dagslysforhold for arbeid uten belysning trengs >5%.
Innetemperatur overskrider komfortgrensen 149 timer i brukstiden i løpet av året, selv med vinduslufting (Inneklimakategori II i NS-EN 15251) *
- Høyeste operativ innetemperatur i brukstiden i løpet av året er 32,3°C (ved utetemperatur 32,3°C, kl.16:00 i august), med vinduslufting. *
*) Det forutsettes væravhengig innetemperatur-komfortgrense for bygg uten mekanisk kjøling, ref. NS-EN 15251:2007 §A.2.

Figure 33: Results sheet

Finally, all data are summarized in one sheet.

Dokumentasjon av kontrollberegning i henhold til NS 3031:2007 / A1:2010

Bygningsbeskrivelse, adresse:	**Bolig-BIM Demobolig**	Byggeår 2013. Kunde/ref: DDS Project
Lokalt klima:	**Oslo**	(Veldig skjermet | Sentrum i storby)
Type kontrollberegning:	**TEK10 §14 (fullstendig kontroll)**	Hele bygningen er beregnet
Beregning utført av:	**Byggmester Ola Norman AS**	v/ Byggmester Ola Norman

SENTRALE INNDATA FOR ENERGIBEREGNINGEN, dokumentert iht. NS 3031:2007 Tillegg J:

Størrelser		Inndata	Dokumentasjon
Bygningskategori		Småhus	Enebolig (1 boenhet)
Arealer [m²]	Yttervegger	222	bl.a. Stående, isolert m/påforing, 13 gips
	Tak	83	Roof-1-1.80
	Gulv	80	Gulv på grunn
	Vinduer, dører, og glassfelt	33	bl.a. Vindu type 4
Oppvarmet del av BRA (A_{fl}) [m²]		167	-
Oppvarmet luftvolum (V) [m³]		400	-
U-verdi for bygningsdeler [W/(m²·K)]	Yttervegger	0,20	-
	Tak	0,13	-
	Gulv	0,11	-
	Vinduer, dører, og glassfelt	1,19	-
Arealandel for vinduer, dører og glassfelt (γ_{sol})		20 %	-
Normalisert kuldebroverdi (Ψ'') [W/(m²·K)]		0,05	-
Normalisert varmekapasitet (C'') [Wh/(m²·K)]		20	-
Lekkasjetall (n_{50}) [/h]		2,5	-
Temperaturvirkningsgrad (η_T) for varmevekslser		70,0 %	-
Årsmiddel temperaturvirkningsgrad for varmegjenvinner pga. frostsikring (men ikke tillufttemperatur-styring)		70,0 %	Avkast>-10°C, Tilluft=18°C.
Spesifikk vifteeffekt (SFP) relatert til luftmengder, i driftstiden [kW/(m³/s)]		2,5	-
Spesifikk vifteeffekt (SFP) relatert til luftmengder, utenfor driftstiden [kW/(m³/s)]		-	-
Gjennomsnittlig spesifikk mekanisk ventilasjonsluftmengde i driftstiden (V_{on}/A_{fl}) [(m³/h)/m²]		1,2	Infiltrasjon (dvs. luftlekkasjer) utgjør ca. 0,42 (m³/h)/m²) i tillegg
Gjennomsnittlig spesifikk mekanisk ventilasjonsluftmengde utenfor driftstiden (V_{on}/A_{fl}) [(m³/h)/m²]		-	-
Årsgjennomsnittlig systemvirkningsgrad for oppvarmingssystemet		149 %	-
Installert effekt for romoppvarming og ventilasjonsvarme (varmebatteri) [W/m²]		47,6	med nattsenking
Settpunkt-temperaturer for oppvarming [°C]		21 (19 om natten)	Ventilasjonsluft settpunkt: 18/18°C sommer/vinter
Årsgjennomsnittlig effektfaktor for kjølesystemet		-	-
Installert effekt for romkjøling og ventilasjonskjøling [W/m²]		-	-
Settpunkt-temperaturer for kjøling [°C]		-	-
Spesifikk pumpeeffekt (SPP) [kW/(ℓ/s)]		0,5	-
Driftstid for oppvarming, kjøling, lys, utstyr, varmtvann / ventilasjon / personer		16 / 24 / 24 timer/døgn	Hhv. 7/7/7 døgn/uke og & 52/52/52 uker/år, jfr. NS 3031
Spesifikk effektbehov for belysning i driftstiden [W/m²]		1,95	J.fr. NS 3031 Tillegg A
Spesifikk varmetilskudd fra belysning i driftstiden (α''_{lys}) [W/m²]		1,95	J.fr. NS 3031 Tillegg A
Spesifikk effektbehov for utstyr i driftstiden [W/m²]		3	J.fr. NS 3031 Tillegg A
Spesifikk varmetilskudd fra utstyr i driftstiden (α''_{uts}) [W/m²]		1,8	J.fr. NS 3031 Tillegg A
Spesifikk effektbehov for varmtvann i driftstiden (α''_{w}) [W/m²]		3,4	J.fr. NS 3031 Tillegg A
Spesifikk varmetilskudd fra varmtvann i driftstiden [W/m²]		0	J.fr. NS 3031 Tillegg A
Spesifikk varmetilskudd fra personer i driftstiden (α''_{pers}) [W/m²]		1,5	J.fr. NS 3031 Tillegg A
Total solfaktor (g_T) for vindu og solavskjerming (Ø/S/V/N)		0,75/0,75/0,75/0,75	Type solskjerming: Ingen
Gjennomsnittlig karmfaktor (F_F)		0,25	-
Solskjermingsfaktor pga. horisont, nære bygninger, vegetasjon, og eventuelle bygningsutspring		0,76	-

KONKLUSJON FRA KONTROLLBEREGNINGEN:

► Boligen tilfredsstiller kriteriene i TEK10 §14 (fullstendig kontroll)

5. november 2012
dato

underskrift

Figure 34

APPENDIX F: Guidelines for information exchange between Revit and DesignBuilder

Buildings Information Models have to be optimized for exchanging with energy analysis tools. This section describes best practices, workflow and tips for creating models in Revit suitable for analysis in DesignBuilder through the exportation to gbXML.

It is important to notice that the energy model may result in a model that does not visually look like the actual design for construction purpose, but provides the properly information for the analysis to be done. For example, DesignBuilder (and other analysis tools) can have difficulty with curved surfaces, so a curved element may have to be split up into multiple small rectangular sub-elements.

GENERAL WORKFLOW

1) CREATE ROOMS OR SPACES: During the gbXML exportation process, the Revit model - which included walls, slabs, roofs, windows and other architectural and building elements- is converted to an Analytical model for energy analysis. In order for the conversion to be possible, *room or space objects* have to be properly placed within the model and volumes and areas setting must be turned on.

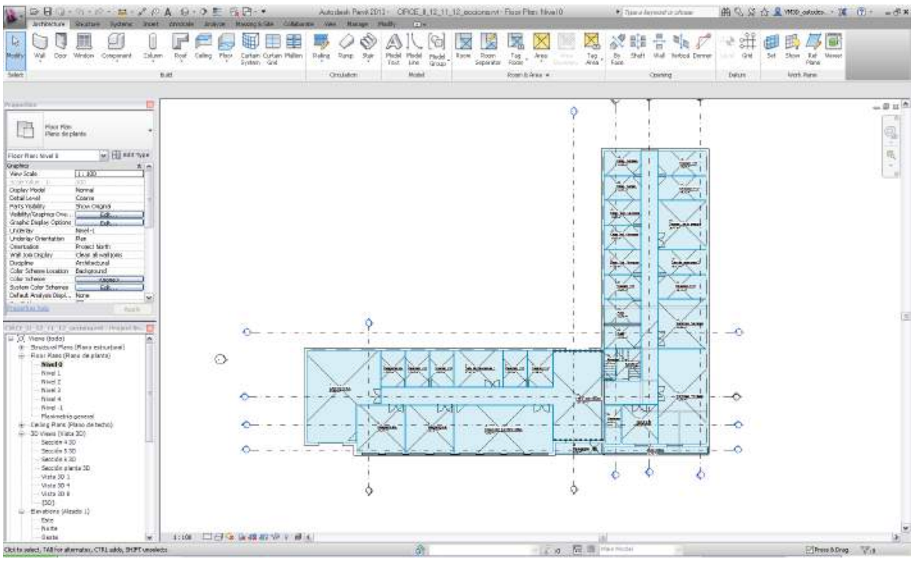


Figure 35: Room objects located in each different termal zone

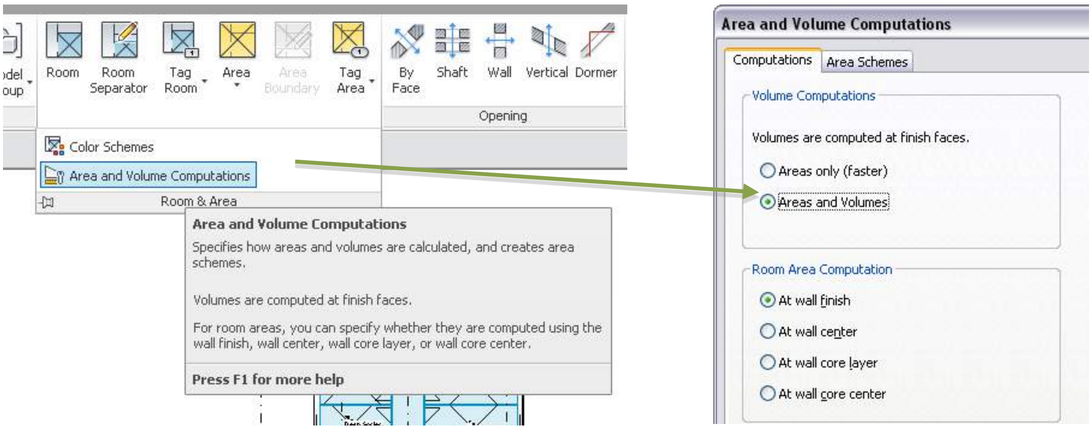


Figure 36: Room's area and volume computations windows

ROOM/SPACES MODELING TIPS:

- Do not allow for any gaps between architectural elements.
- Do not use in-place families to build typical bounding elements. Use the native tools for windows, walls, floors, roof, etc.
- Ceilings are not used as bounding elements in an analytical model.
- Do not include shaft or stairwell openings. These elements could cause problems in the analytical model interpreted by DesignBuilder.
- Centerlines of walls must be aligned, since the analytical model reads to the center of the wall.
- All roofs should be modeled with the roof tool.
- Do not include columns, so make them *non-room bounding*, since columns do not provide any significant meaning to the energy model because the reduced space volume is so small in comparison to the large scale energy model.

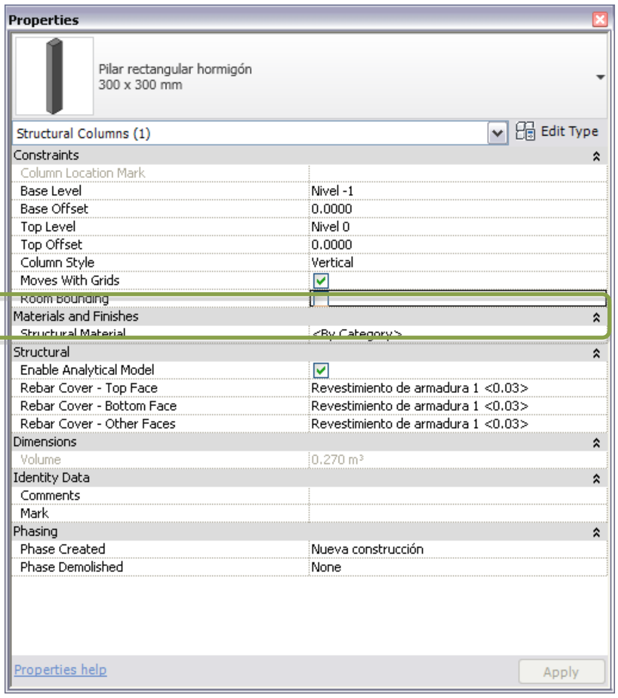


Figure 37: Column's properties window

- Curtain walls in the analytical models will be represented as a wall surfaces and every panel in the Curtain wall is a window opening. If the assigned material for the Curtain wall has less than 3% transparency, it will be treated as a solid panel. The *Automatically Embed* instance parameter should be checked. Sometimes, it could cause mistakes in the area of the Curtain Walls, in those cases it is recommended to use a simple window to represent Curtain Wall by extending the window from the floor to the next level.

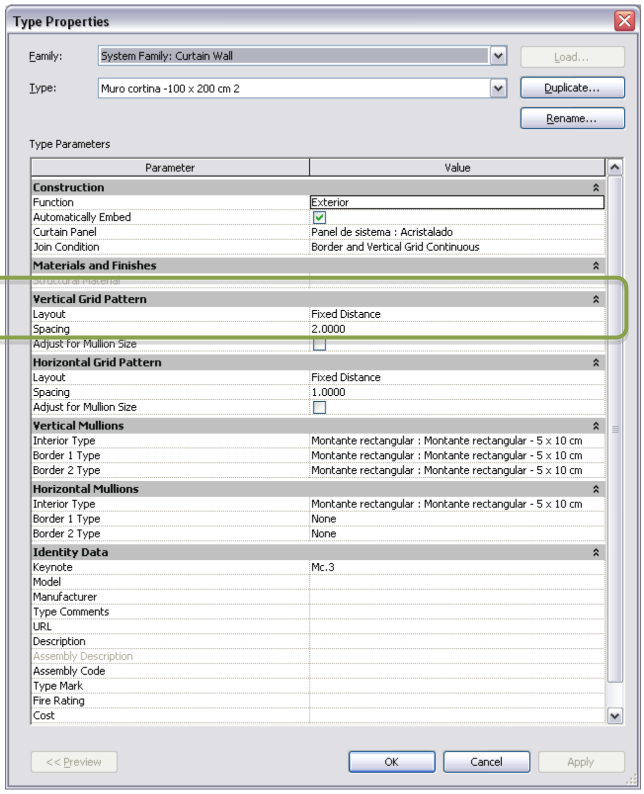


Figure 38: Curtain wall's Type properties window

2) DEFINE LEVELS: It is important to adjust upper and lower boundary using section views. Make sure that the rooms fill the area within the model horizontal and vertically.

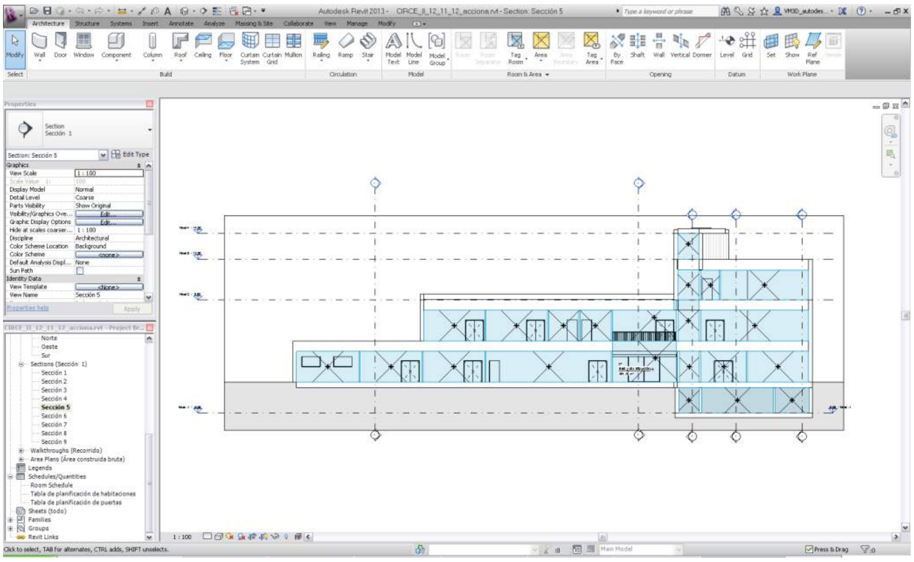


Figure 39: Room objects located by level

Next picture represents different ways of creating rooms and spaces in Revit. Option 1 is incorrect because in DesignBuilder will appear some gaps between floors. The right way is adjusting rooms or spaces not to leave gaps between them.

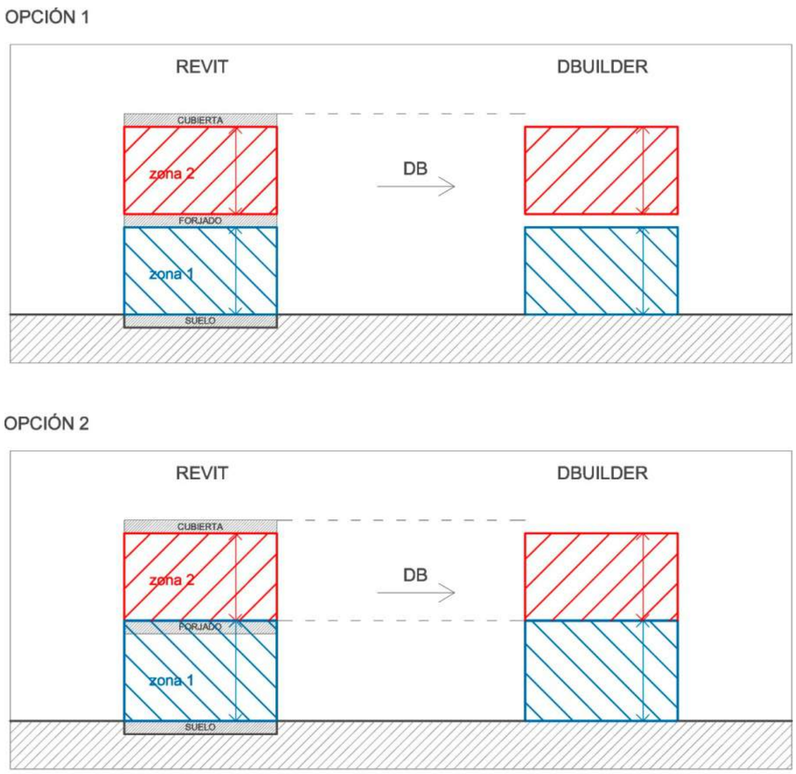


Figure 40: Room or spaces from Revit to DesignBuilder

For multilevel buildings, spaces should be added to one level at a time.

3) INSERT PROPERTIES: The only property needed for the export to work is the *Occupiable parameter*.

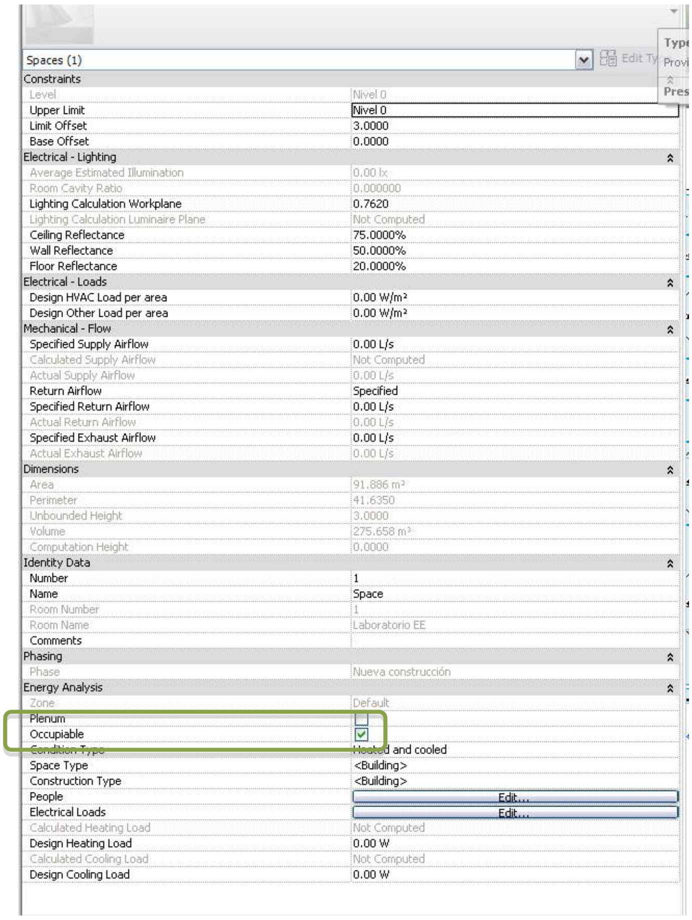


Figure 41: Space object properties window

4) EXPORT TO gbXML: Before any exportation is done, certain settings must be checked (see image below):

   a. Select building type, based on ASHRAE standard.

   b. Set Location (if it has not defined previously).

   c. Set ground plane, based on the levels created in the model.

   d. Set export category (rooms or spaces).

   e. Set export complexity. Choose as simple as possible.

   f. Set Project phase. Spaces and rooms must be placed in the same phase as the Project Information phase.

g. Set Sliver space tolerance. Too much sliver space may allow air flow thermal transfer between zones that in reality do not occur.

h. The box for including Thermal Properties is irrelevant for exporting to DesignBuilder.

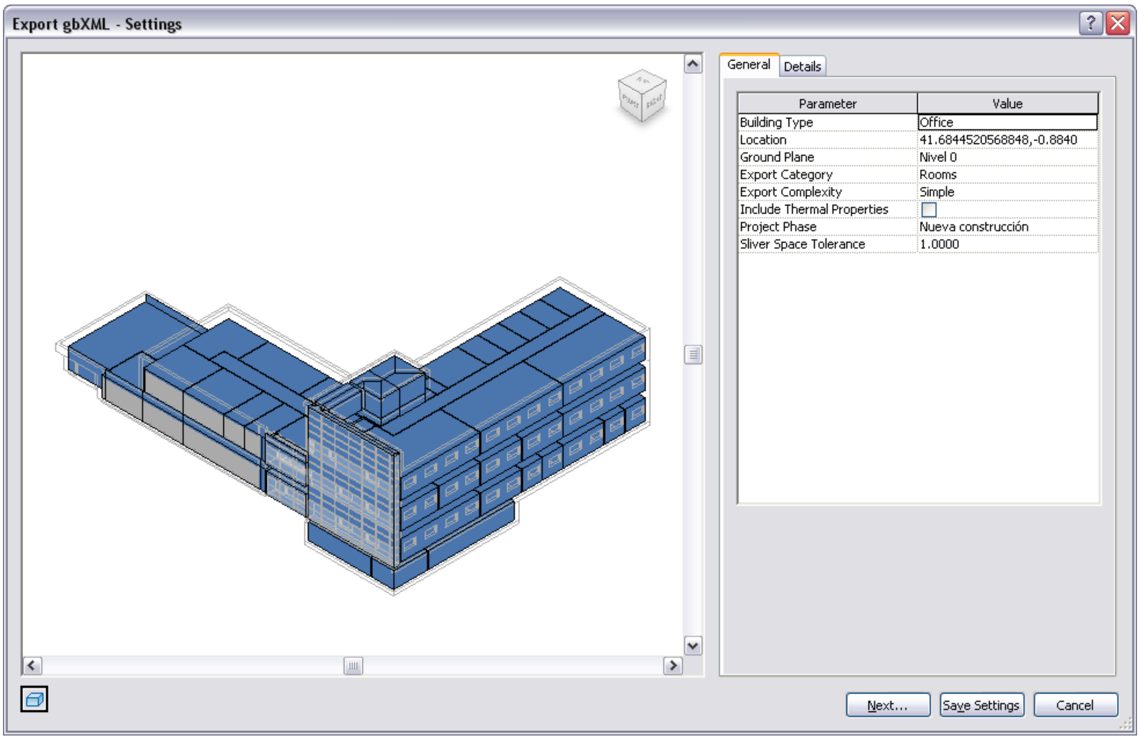
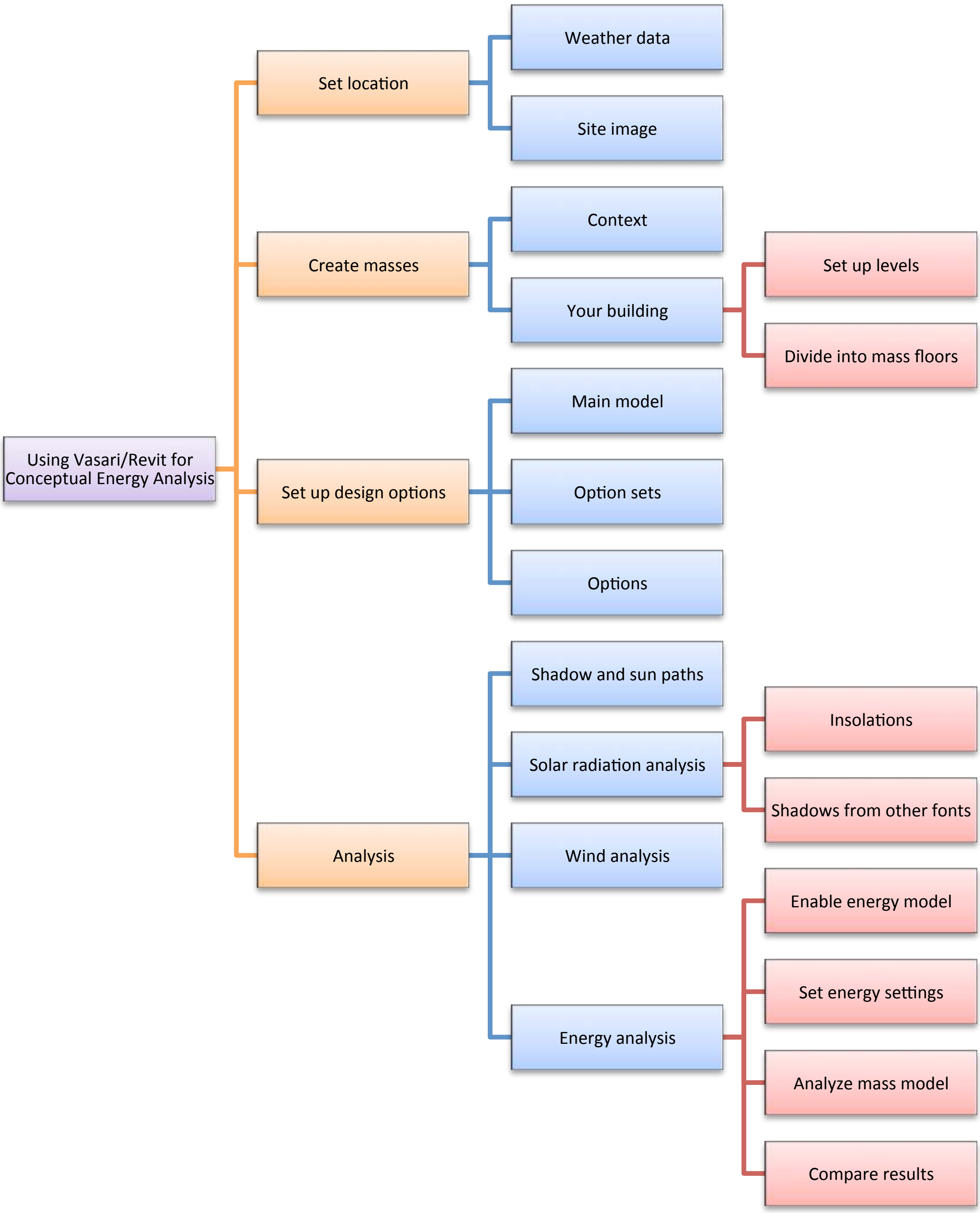


Figure 42: Export gbXML settings window

APPENDIX G: Conceptual Energy Analysis in Revit or Vasari

Next diagram shows the process of using Vasari or Revit for conceptual energy analysis[13].



[13] Source: Standford University – CEE 110/210 Building Information Modeling

This is not a linear process but an iterative one consisting of a series of recursive steps, modeling and evaluating differing design options and alternatives.

1. Set location
   Specifying an exact location is important for energy analysis and simulations as it is associated with weather data used. This process brings in a specific latitude, longitude, and weather data relative to the project site, and imports a base satellite image to build the massing model relative to the site context.

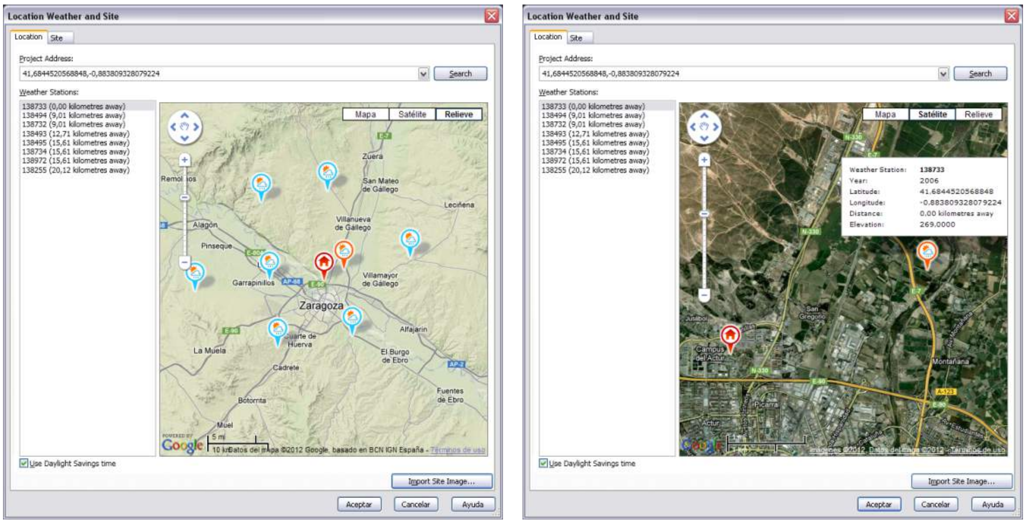


Figure 43: Location Weather and site window

2. Create masses
   The levels created as reference planes are used as floor datum to create floors in the masses. These are calculated as floor to floor heights and will define the floor areas to measure. It is useful to model adjacent buildings and terrain to test the influence between them.

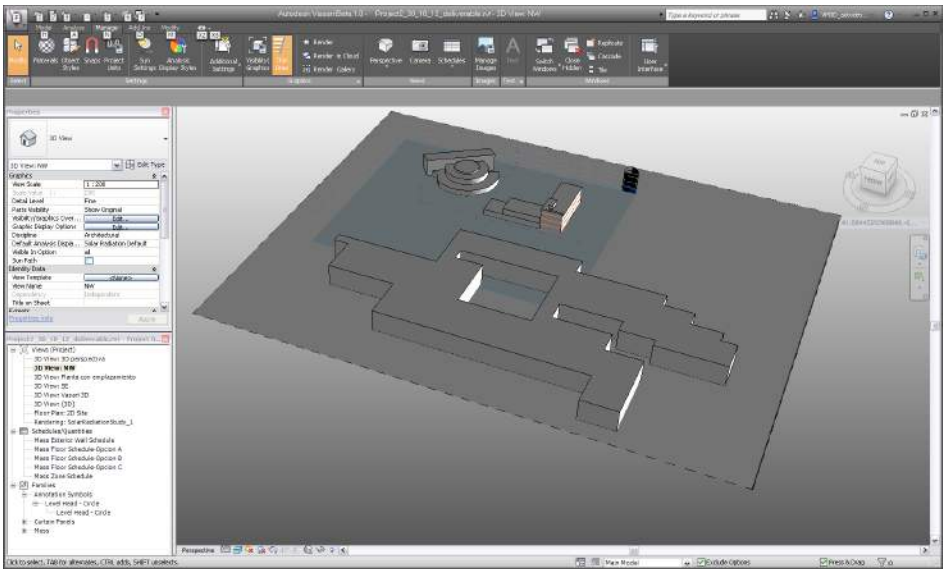


Figure 44: Conceptual mass model

3. Set up design options

   Design options is a framework for modeling, analyzing, and visualizing iterations during design. It allows quick changes exploration. When a parametric model is created within a design option set, it is easy to make some changes and compare the differences between options through a conceptual energy analysis. After energy analyses have been run, the results can be compared side by side and an informed decision about the design can be made. Parameters can be added to make adjustments to the design or to constrain form to particular values.

   Next pictures depict different options of a same building design.

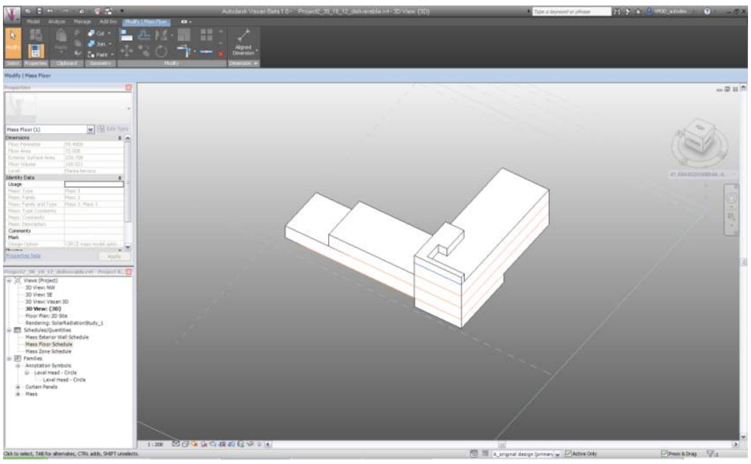


Figure 45: Option A - Original design

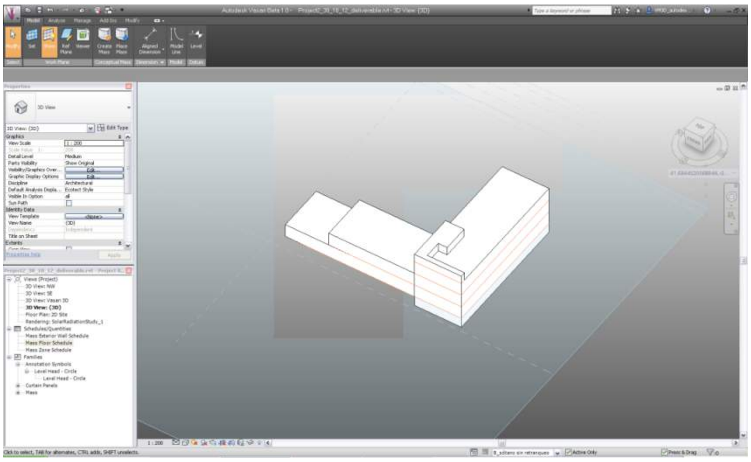


Figure 46: Option B - Larger basement

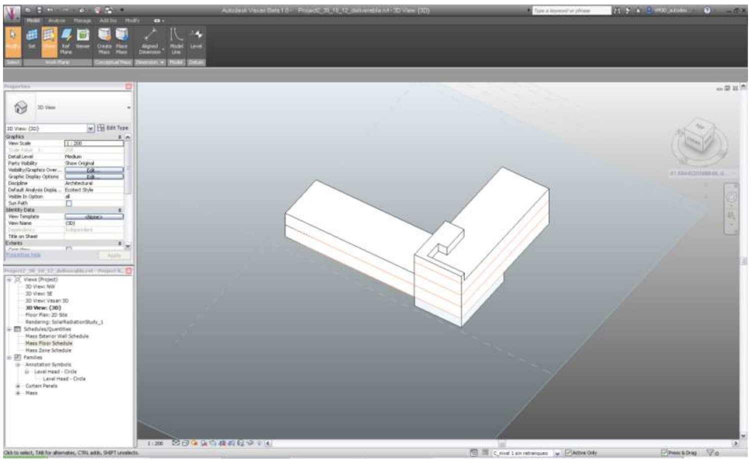


Figure 47: Option C – Larger first floor

4. Run Analyses

   The analyses included in Vasari and Revit are:

- Sun path which allows studying shadows generated by the sun during all the year. The study can cover a day, a year or a specific period of time defined in the tool's settings.

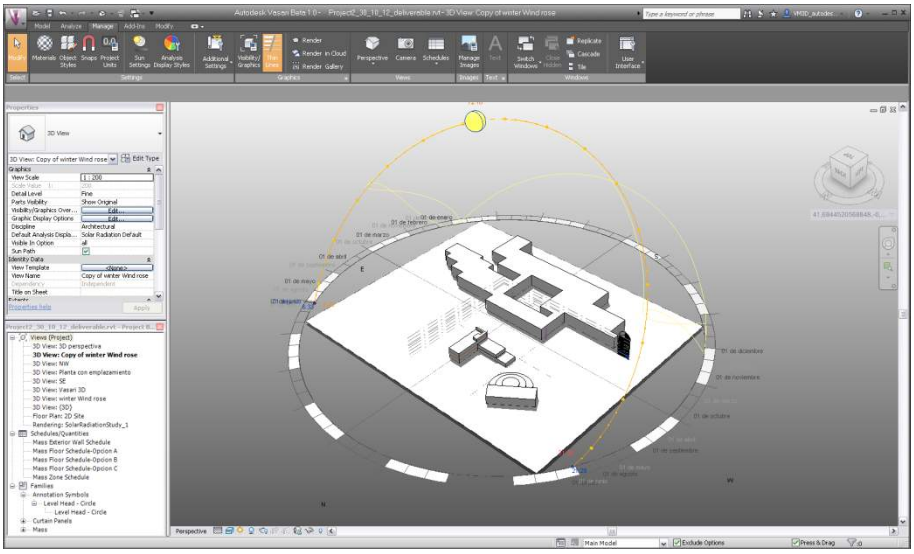
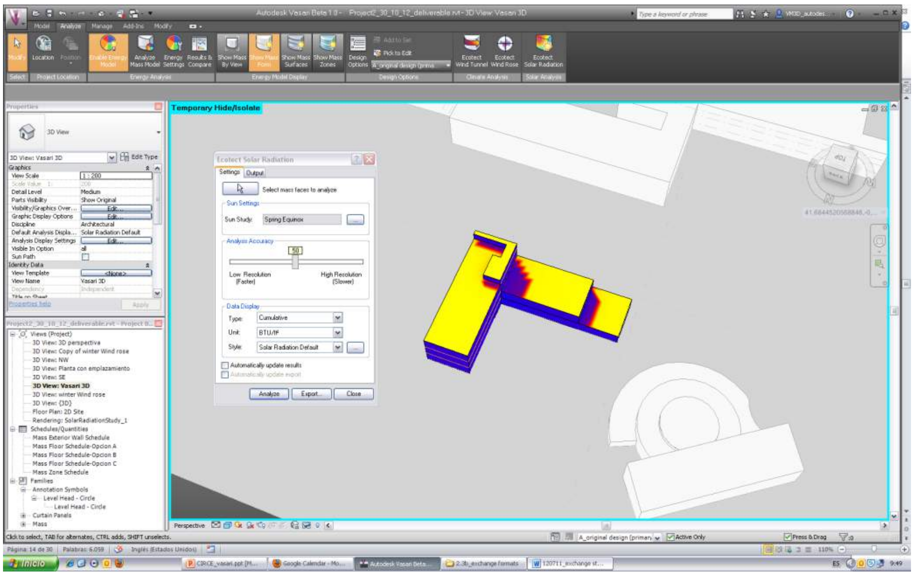


Figure 48: Sun path tool

- Solar radiation tool to look at the impact of solar radiation on the design, it simulates the amount of sun energy transmitted to a surface (or all building surfaces) at a specific time based on the buildings position relative to the sun.



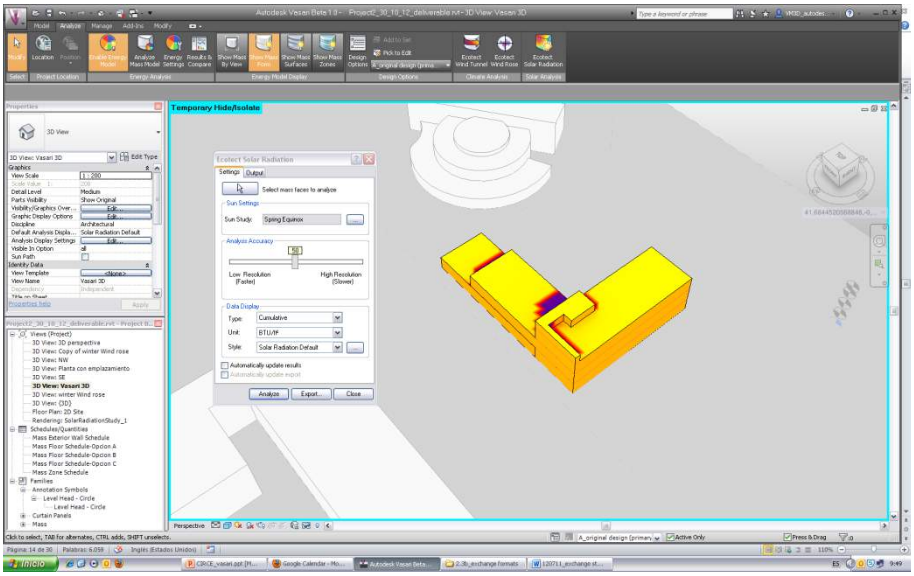
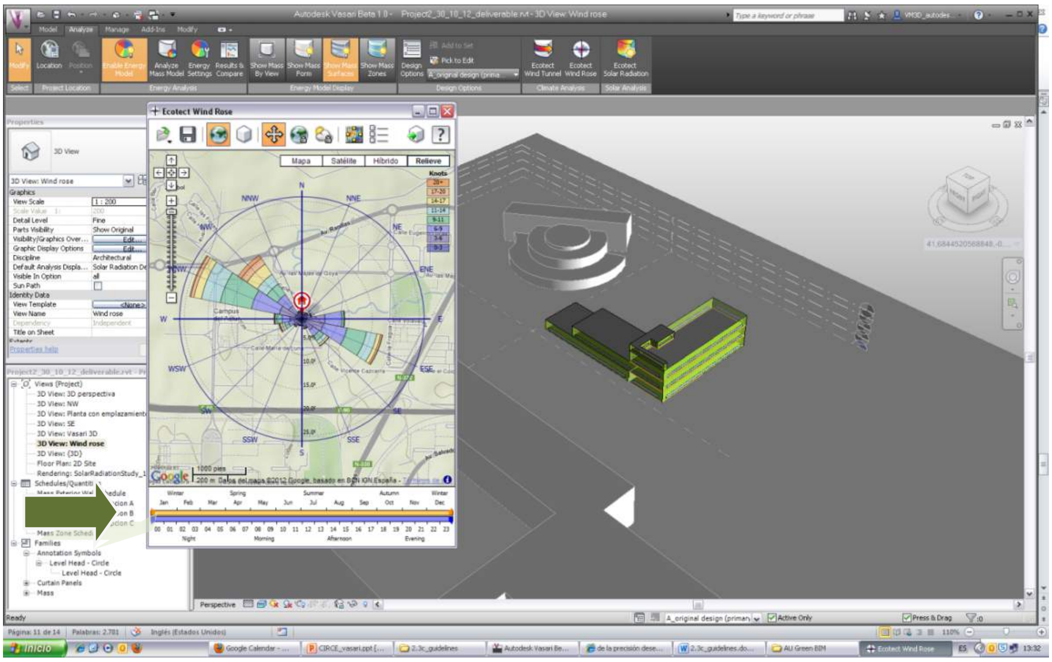


Figure 49: Spring equinox solar radiation analysis

- Wind analysis. In the wind rose tool is possible to set a specific month and time, to differentiate, for instance, winter wind among winter and summer wind. The winter wind rose will reveal the directions of the wind we are trying to protect our users from, whereas the summer wind rose will reveal wind we are trying to capture for the purpose of passive cooling through natural ventilation



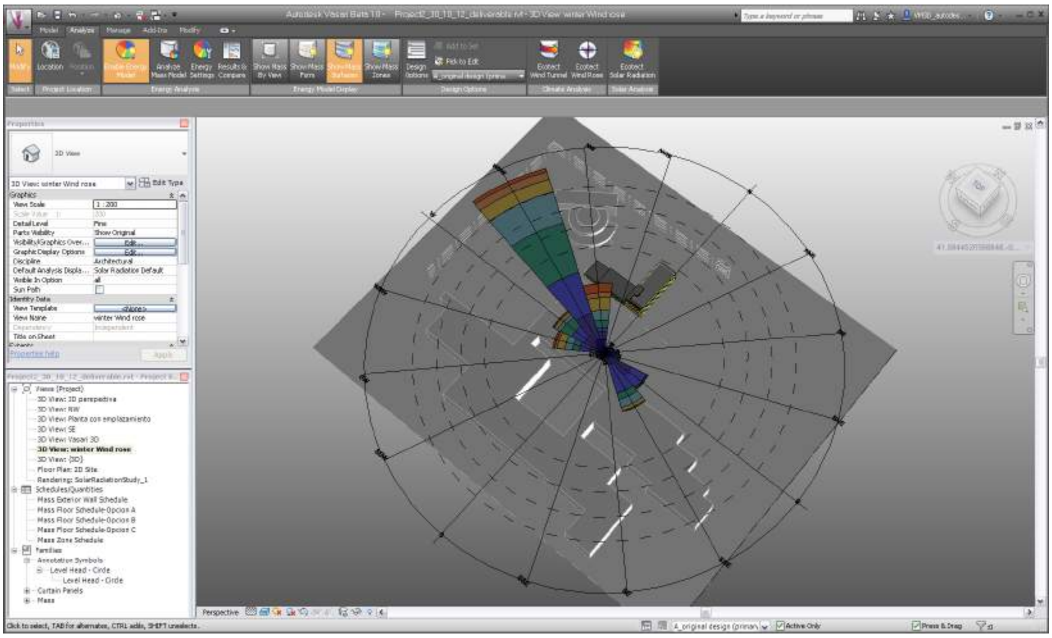


Figure 50: Wind rose tool in Vasari

- Wind tunnel analysis allows understanding wind motion in and around physical forms. This tool is more observational than data-oriented. Modifying the settings, we can display the information in different ways.

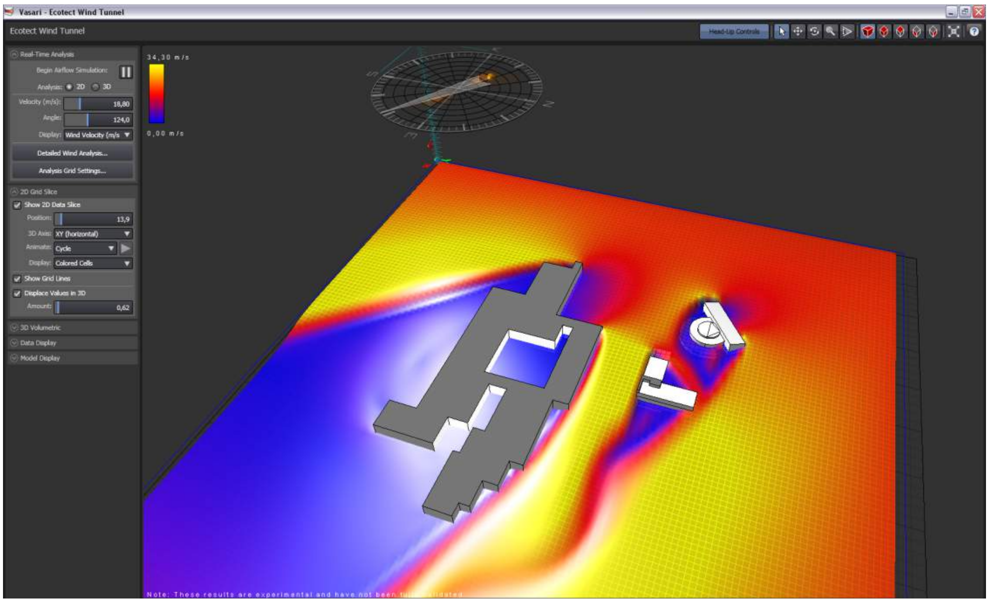


Figure 51: Wind moving represented as a 2D plane across the site

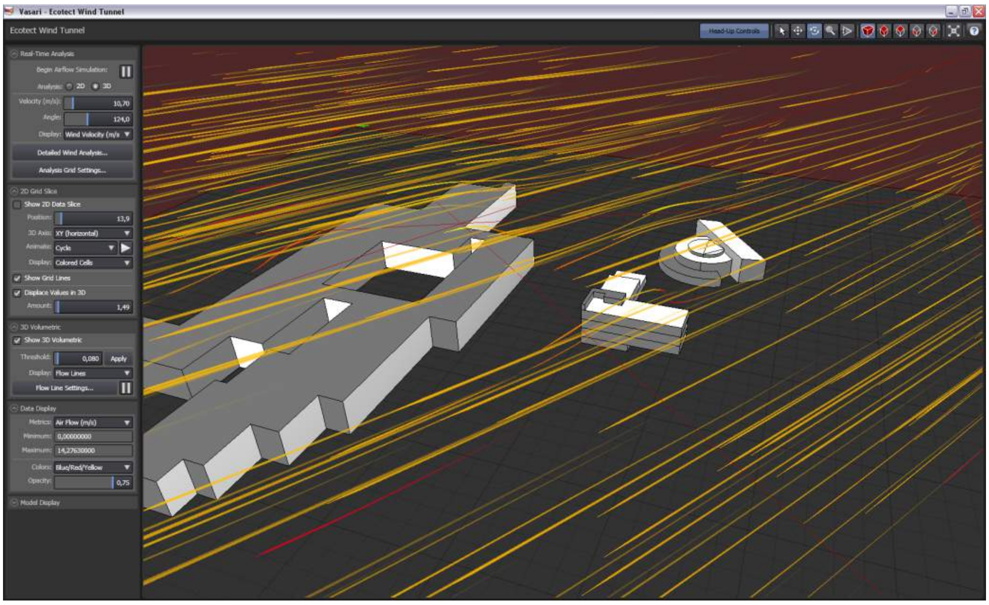


Figure 52: Wind moving represented as a 3D series of lines across the site

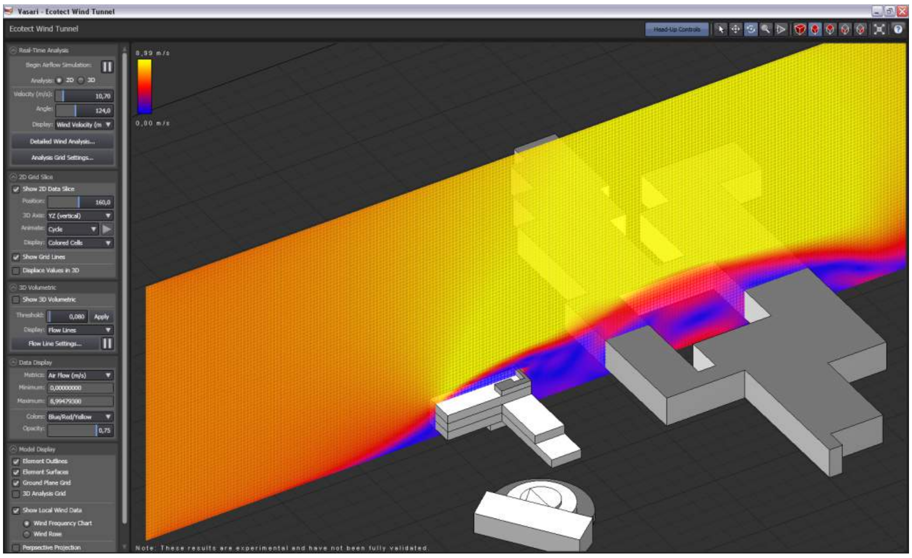


Figure 53: Wind moving represented as a 2D plane cutting through the building section

- Whole energy analysis tool. Running a test of the options that have been set up will send the model information to a cloud-based service that will in turn automatically generate an energy report which is well-organized, concise and graphic. In addition to being able to easily visualize what parameters are influencing the results the most, there is also the ability to easily compare multiple conceptual designs.

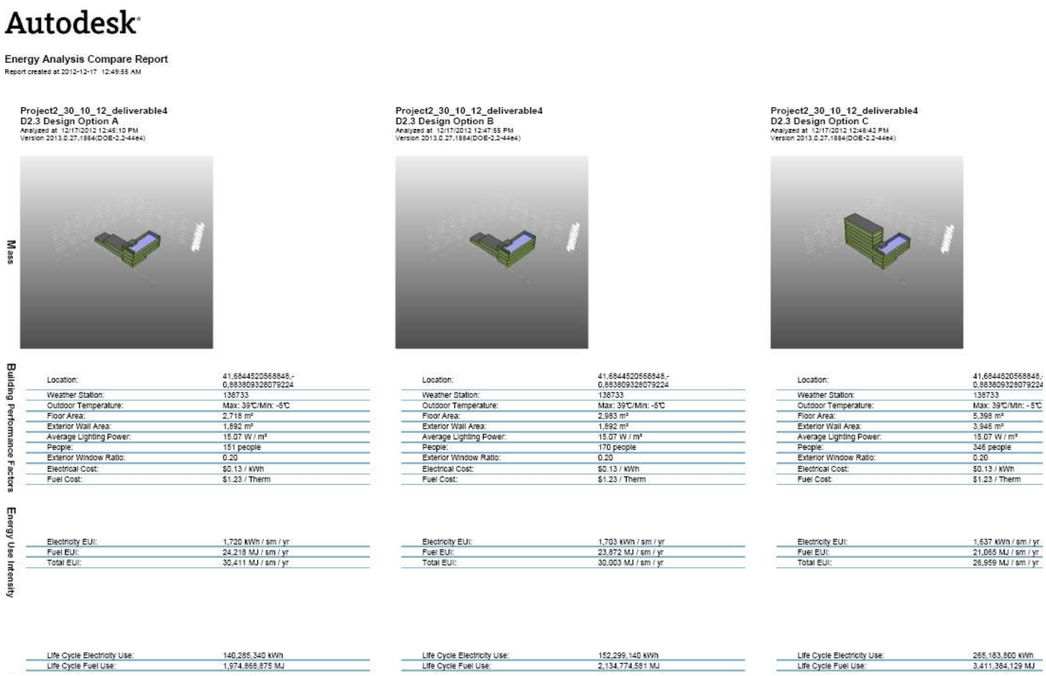


Figure 54: Comparison of results between design options

APPENDIX H: BIM modeling and analysis plan template

Project description

Introduce key information about the Project

Project Name	
Project Address	
Project brief description	
Project's Owner	
Phases / Milestones	*Estimated start and completion dates, project stakeholders involved*
Other relevant information	

BIM goals and uses

Describe project goals related to BIM. They can be based on energy analysis and simulation or not. For instance, a goal related to energy could be 'more energy efficient design through conceptual energy analysis' and another goal not related to energy but general project performance could be 'reducing the project schedule duration'.

Once goals have been identified, they have to be related to those BIM uses which allow achieving the objectives. BIM uses related to energy analysis have been described throughout this document (deliverable 2.3); however there are many other potential uses of BIM. For further information, the Computer Integrated Construction Research Group of the Pennsylvania State University has elaborated a complete list of uses[14].

BIM Goal	BIM Uses	Priority (high, med, low)

[14] *http://bim.psu.edu/Uses/default.aspx*

BIM team

For each BIM use, the roles and their specific responsibilities must be defined. This includes the contact information of the staff involved. [BIM roles chart previously completed in task 2.3 can be used for this section].

Fill in this chart with the details related to the people in charge of developing the BIM mode/s, indicating the role of each one (i.e. Architectural modeler, structural modeler, MEP modeler, BIM coordinator…)

NAME and Role in the BIM team	COMPANY	CONTACT INFO (mail, telephone)	BIM Use and SOFTWARE/S used or to be used

Planned models and exchanging with analysis tools

Throughout a project, the project team may generate multiple models. For instance, the Designers' team may generate a 'Design model' and the Contractor's team may generate a 'Construction model' to simulate construction and analyze the constructability of the building. Other 'different analysis models' may be generated, depending on the type of analysis planned.

Outline the models to be created in the project, listing model name, model content, the project phase when the model will be generated, and the software tool to be used.

Model Name and Responsible Rol	Model content	Project Phase	Software authoring tool	Exported to (software) and format
Conceptual energy analysis model / Architecture Team	*Rough energy model with simplified building envelope, thermal zoning and data of window coverage*	*Conceptual or schematic phase*	*Autodesk Vasari*	*Non exported*

Modeling standards

Methods to ensure model accuracy and comprehensiveness by all stakeholders involved should be described in this section:

- *Standard file naming structure*
- *Method to separate large models (e.g. by building, by floors, by specific areas…)*
- *The measurement system (m, cm…) and coordinate system (georeferenced/origin point) to be used to allow for easier model integration.*
- *Level of detail*[15]

BIM-based project deliverables

Some projects have specific requirements, so it is important to document those requirements related to BIM. This way the team is aware of the requirements and can plan accordingly to deliver them.

Project Deliverable Name	Phase	Deadline	Format and Brief description

[15] American Institute of Architects Document E202 – 2008 Building Information Modeling protocol Exhibit. http://www.aia.org/contractdocs/training/bim/aias078742